第7讲: 可见光通信（ Visible Light Communication ）

Outline

- Part 1
  - VLC 简介
  - LED 简介
  - VLC 潜在应用
- Part 2
  - VLC 组件
  - 技术挑战

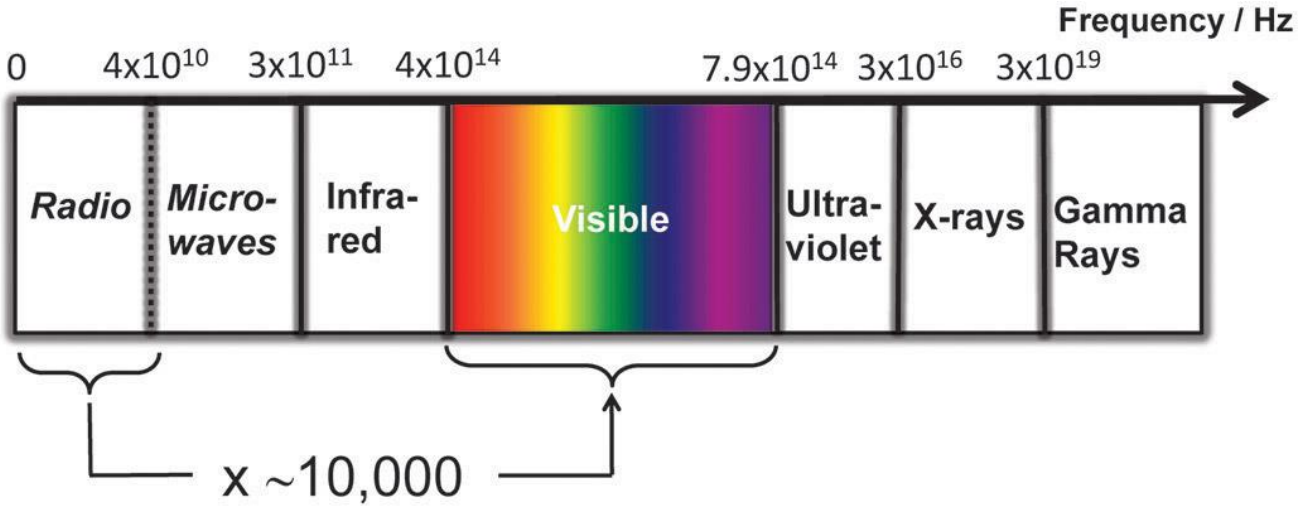
VLC 简介

- **可见光通信 (VLC, Visible Light Communication)**

  : **New communication technology using “Visible Light”.**

- **可见光**

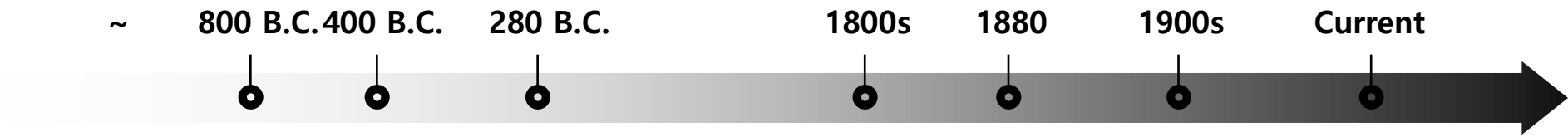
  : **波长~400nm (750THz，紫光) and ~700nm (428THz，红光)**



VLC 简介（2）

- **一般特征**
  - 可见性（ Visibility ）: Aesthetically pleasing (美观)
  - 安全（Security）: What You See Is What You Send.
  - 健康（Health）: Harmless for human body and electronic devices
  - 不受监管（Unregulated）: no room to use more radio frequency （无管制）
  - 在禁区内使用（Using in the restricted area ）: aircraft, spaceship, hospital
  - 眼睛安全（Eye safety）

VLC 历史



Sunlight
日光

Heliograph
（日光反射器）

Photophone
By Bell
（光电话）

Fire
火

Beacon
Fire
（烽火台）

Pharos
Lighthouse
（法罗斯灯塔）

Burning Kite
In Battle
（战火中的风筝）

Lamp
灯

Ship-to-ship
Comm.
（船到船通信）

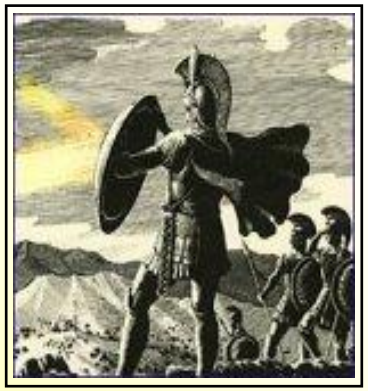
Traffic Light
/Signboard Light
（红绿灯/标志灯）

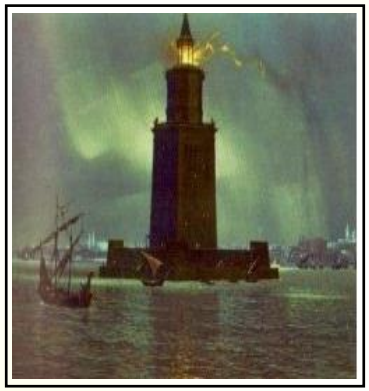
LED
发光二极管

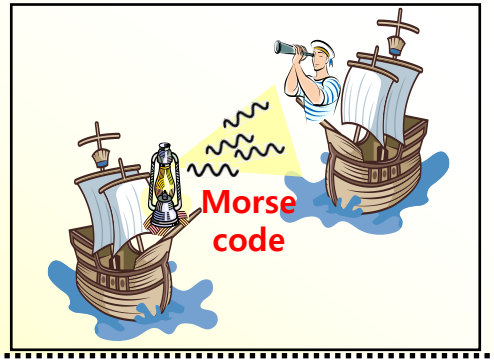
VLC

VLC 历史 – 低速

- 镜子反射信息传递(Heliograph，日光反射器)
- 用火或灯
  - Beacon fire(烽火台), Pharos lighthouse(法罗斯灯塔), ship-to-ship comm. by Morse code (1800s)
- 红绿灯：按颜色区分信号（步行/停止）



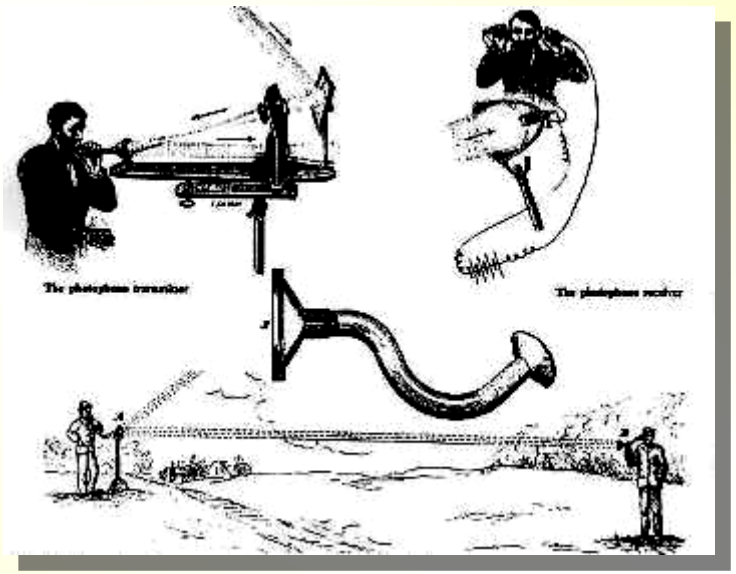




VLC 历史 – 光电话

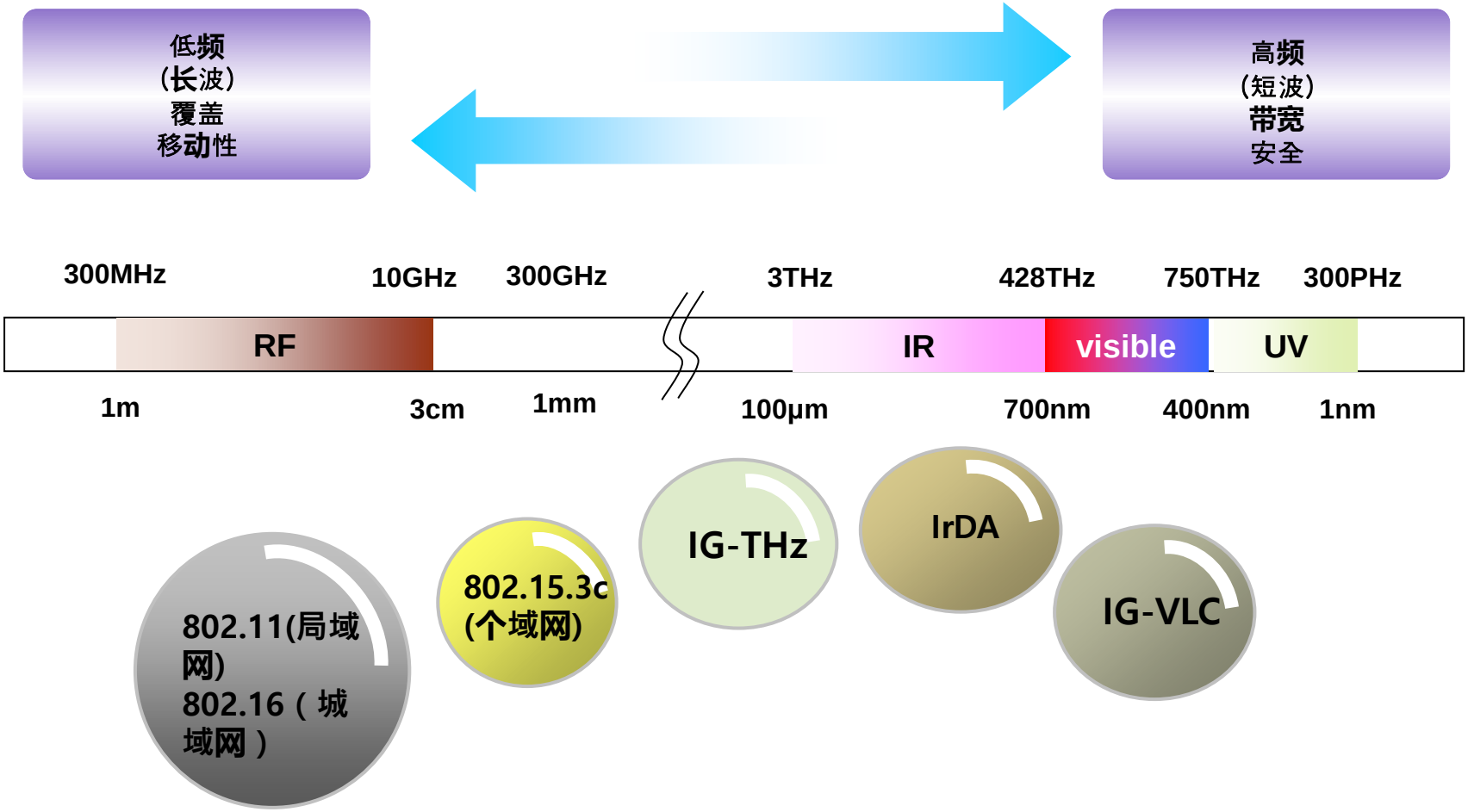
- Bell's Photophone (光电话，1880)
  - 光源：阳光
  - 振动镜外调制
  - 接收器：带有结晶硒网格的抛物面镜
  - 700英尺（213米）声音传输

http://www.freespaceoptic.com/



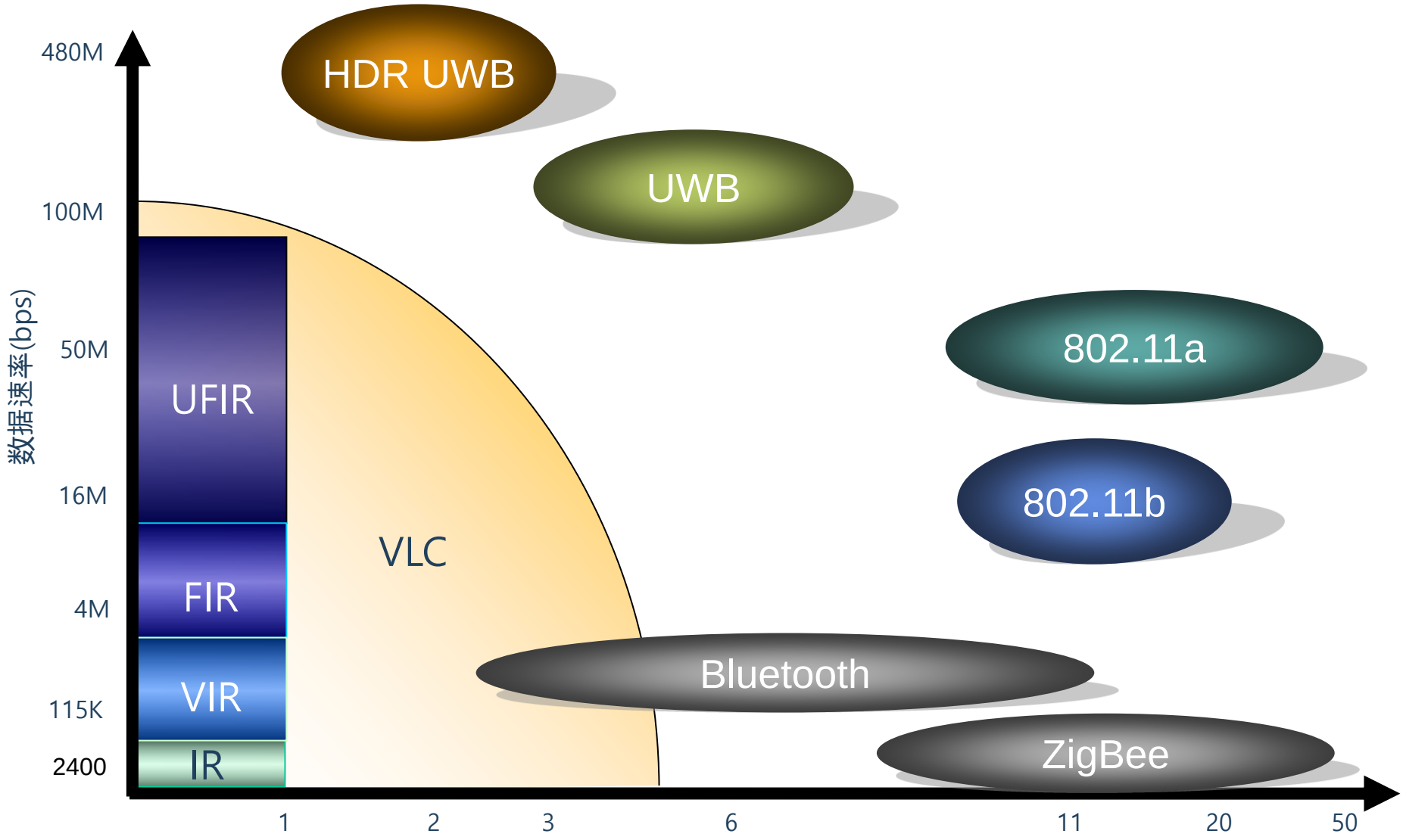
Excerpted from: The New Idea Self-Instructor edited by Ferdinand Ellsworth Cary, A. M. (Monarch Book Company, Chicago & Philadelphia, 1904)

VLC频段

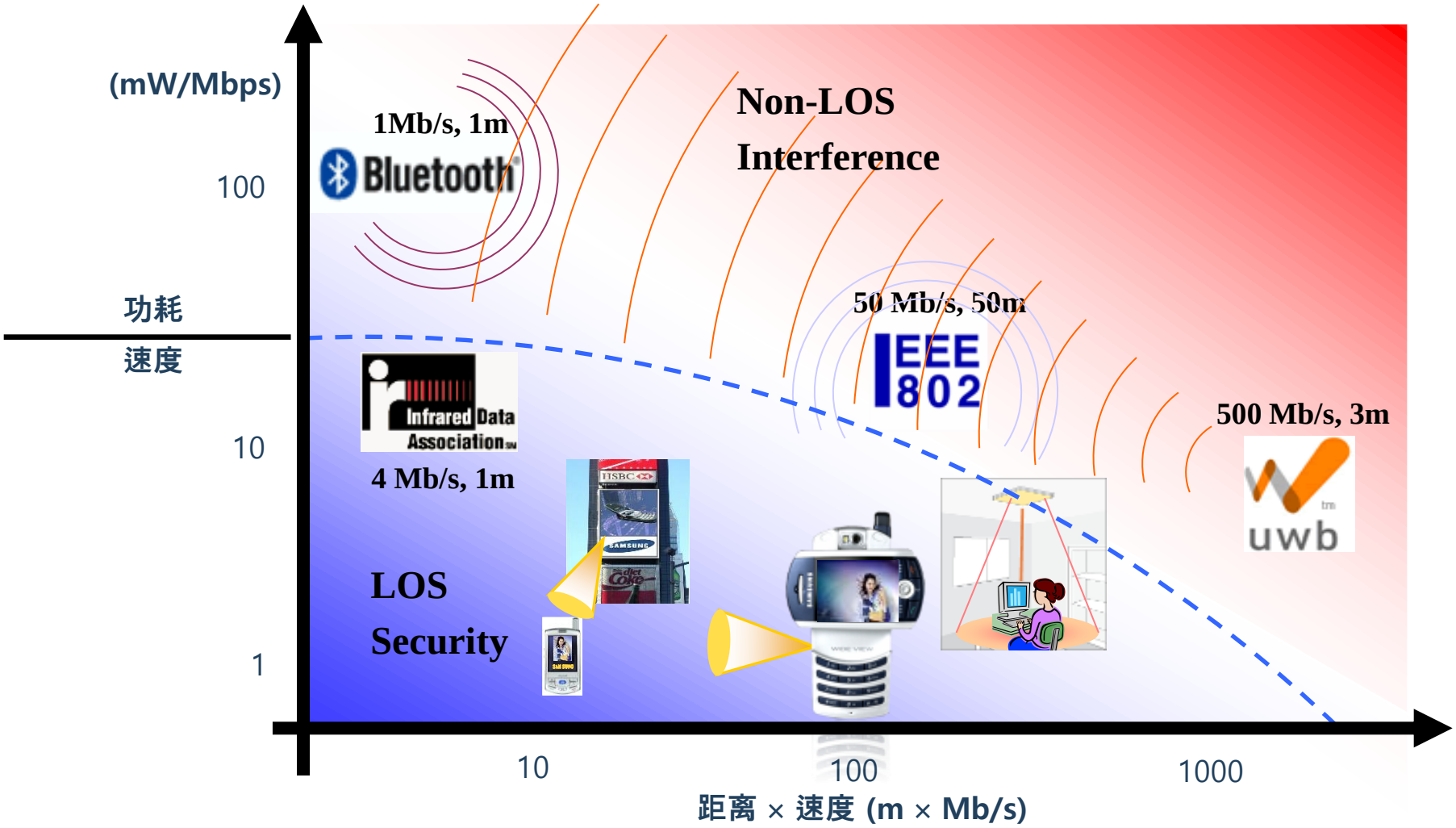


- IG-THz（IG太赫兹）：contribution 15-07-0623-01, AT&T实验室讨论了太赫兹频段，覆盖300 GHz到10太赫兹.
- 该毫米波-WPAN将在包括57-64GHz未授权频段在内的新的清晰频段上工作.
- 毫米波WPAN将允许与802.15 WPAN系列中的所有其他微波系统高度共存（紧密的物理间隔）.

VLC 特征


480M
100M
50M
16M
4M
115K
2400
数据速率(bps)
HDR UWB
UWB
802.11a
802.11b
UFIR
FIR
VIR
IR
VLC
Bluetooth
ZigBee
1
2
3
6
11
20
50
距离 (m)

VLC 特征



方向性+简单性 → 光的连接省电

VLC vs. RF 特征

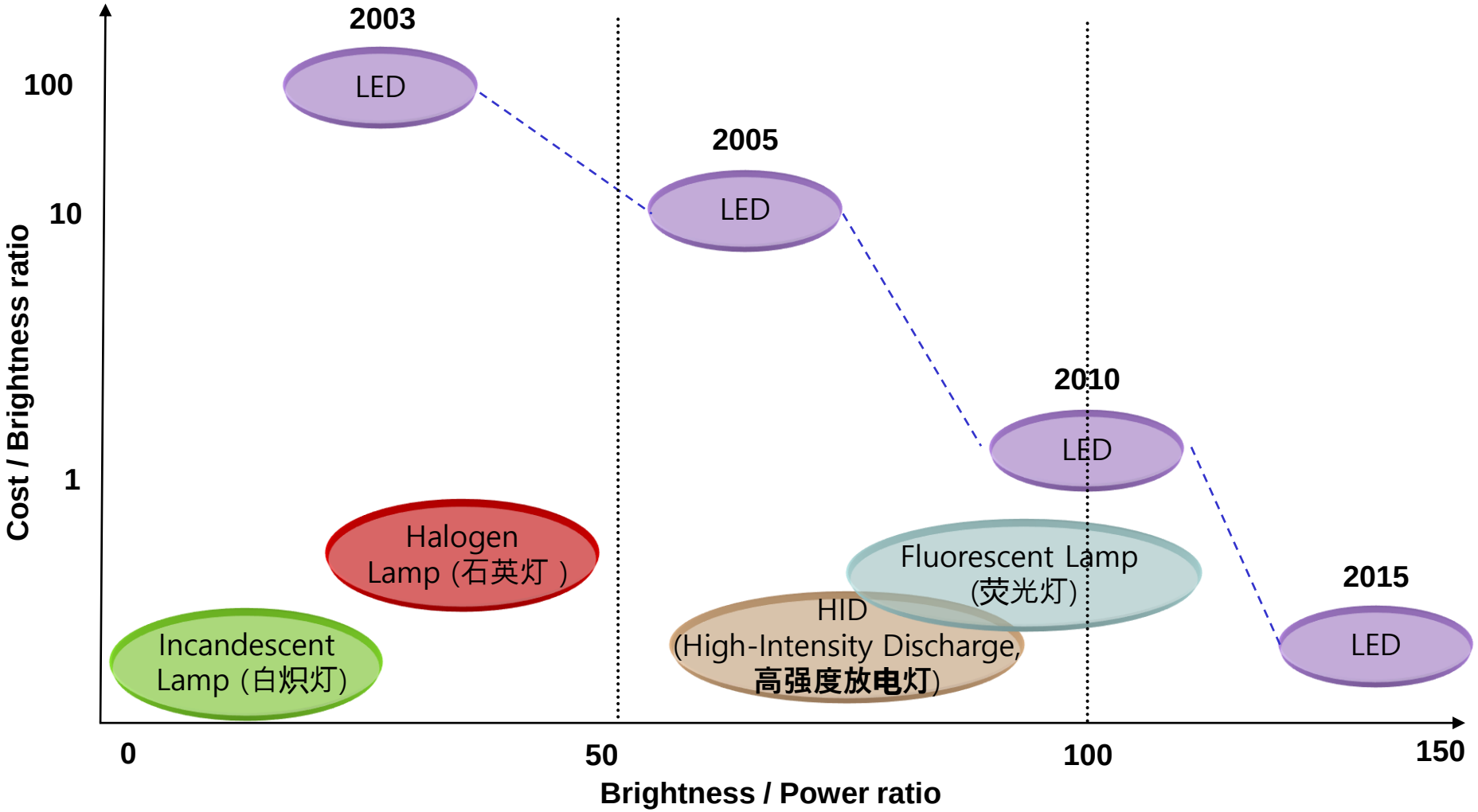
属性		VLC	RF
带宽		Unlimited, 400nm~700nm	Regulatory, BW Limited
对外干扰（EMI）		No	High
视线（Line of Sight）		Yes	No
标准		IG-VLC	Yes
危害		No	Yes (H_2O reaction to 2.4GHz)
Mobile To Mobile	可**见**性（安全性）	Yes	No
	耗**电**量	Relative low	Medium
	距离	Short	Medium
	功率**预**算	Tight	Medium
Infra to Mobile	安全性	Yes	No
	基**础设**施	LED Illumination(照明)	Access Point
	移**动**性	Limited	Yes
	覆盖 (距离)	Short (~10m)	Wide (Short ~ Long Range)

VLC 发展动力

- **通信技术发展趋向**
  - 无处不在（随时随地互联）
  - 安全
- **LED 趋势**
  - LED技术（效率、亮度）
  - LED成本
- **环境趋势**
  - 健康
  - 节能
- **VLC的固有特性**
  - 可见性
  - 无干扰/无调节

LED技术演进

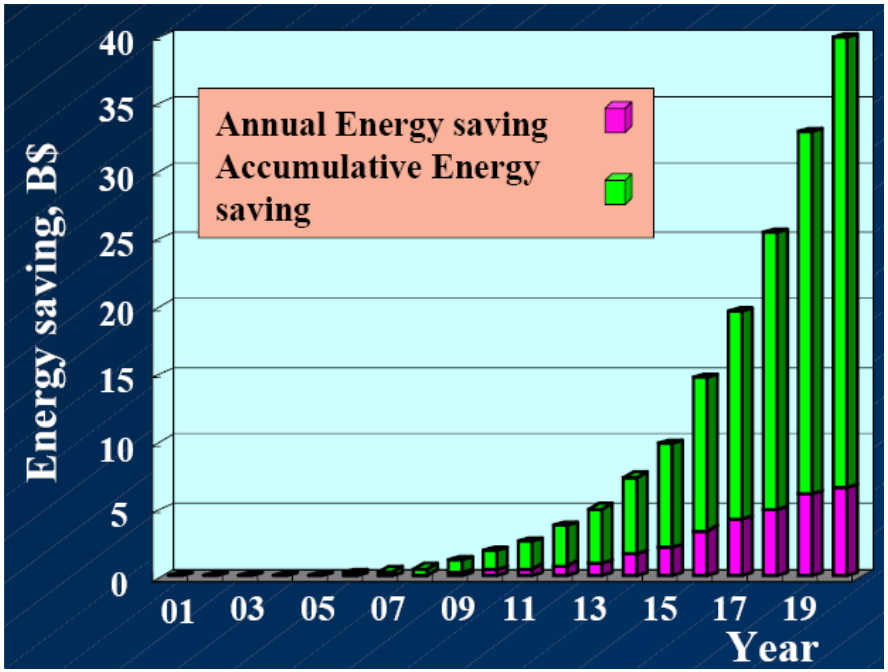
❖性能和价格比较



Source: Credit Suisse, 2006.11.2

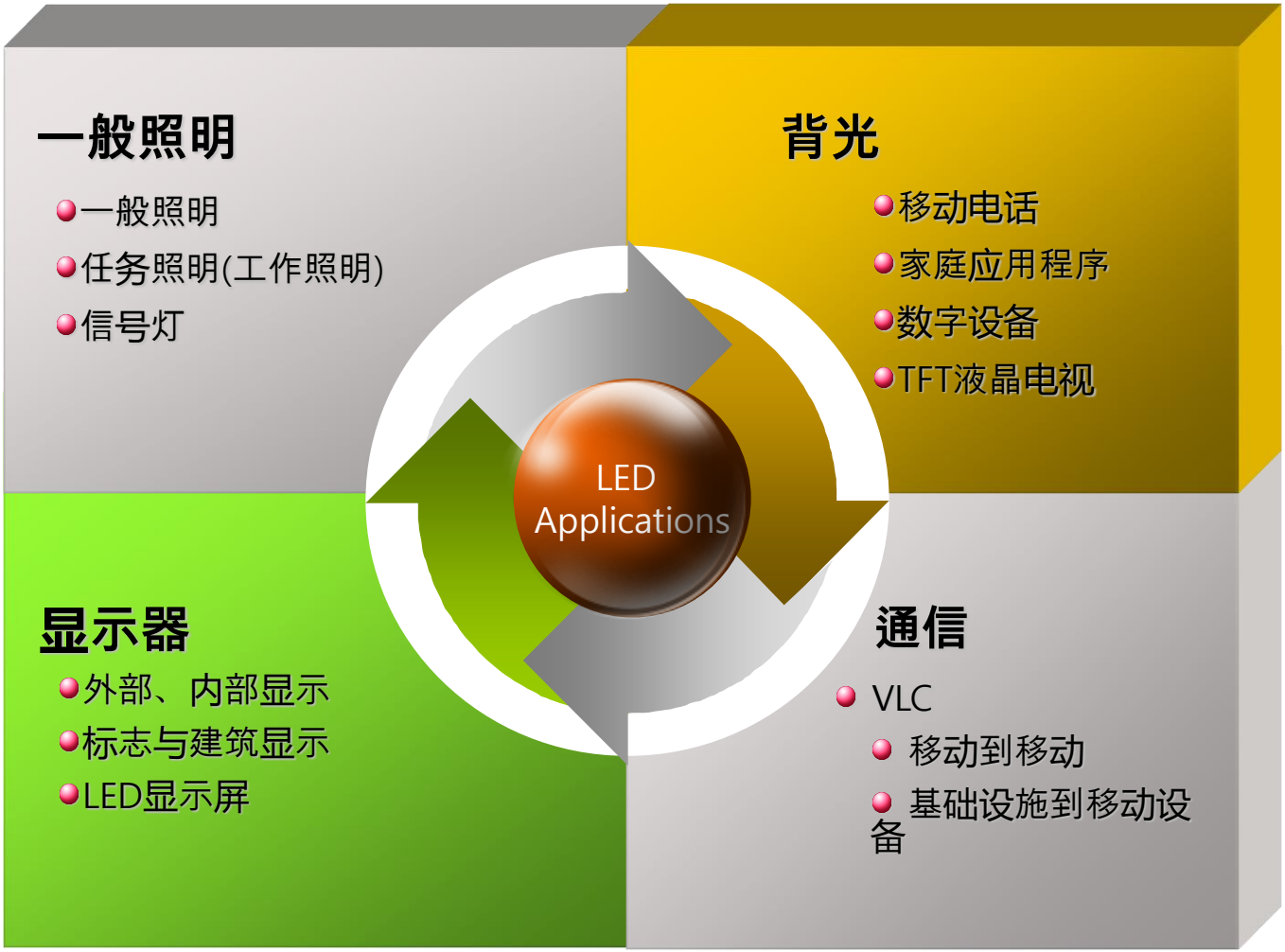
LED driver

- Air Pollutions(空气污染)
  - UNFCCC (United Nations Framework Convention on Climate Change,联合国气候变化框架公约), Kyoto Protocol(京都议定书) to the UNFCCC
    (Dec. 1997)Decreasing CO2(10 k ton/year, 2002 at Korea)
- Waste Materials & Environmental Hazards
  - RoHS (Restriction of the use of Certain Hazardous Substance,限制使用某些有害物质): 1, July 2006.
    Pb(铅), Hg(汞), Cd(镉), Cr6+, Polybrominated biphenyls(PBB,多溴联苯),
    Polybrominated diphenyl eters(PBDE,多溴二苯醚)
  - WEEE (Electrical and Electronic Equipment)
    Producer Responsibility
- Energy saving effect
  - Electricity at Korea
    278 TWh(万亿瓦时),2002, 7.2 % of USA
  - 20% for Lighting:55.6 TWh
  - 50% saving by LED:27.8TWh
  - Energy Saving Effect:
    3 Nuclear Stations (1GW/day)
    2 B$/year

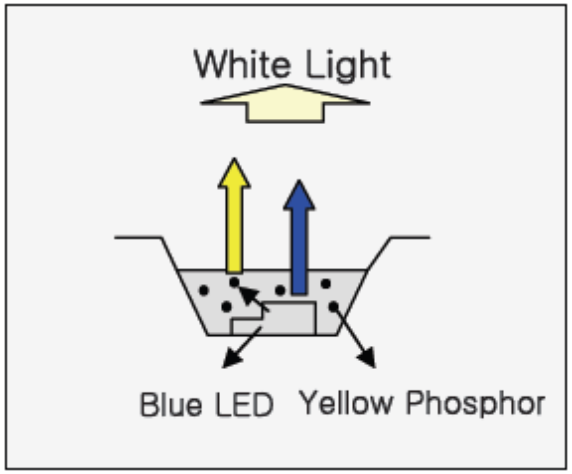


Source: KOPTI (The Korea Photonics Technology Institute)

LED 应用

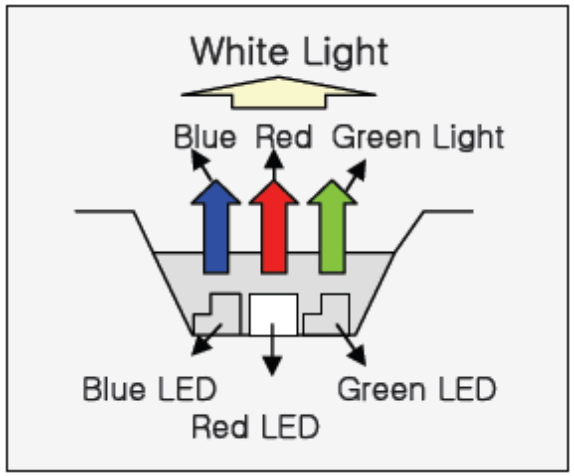

一般照明
一般照明
任务照明(工作照明)
信号灯
背光
移动电话
家庭应用程序
数字设备
TFT液晶电视
LED
Applications
显示器
外部、内部显示
标志与建筑显示
LED显示屏
通信
VLC
移动到移动
基础设施到移动设备

LED调制特性



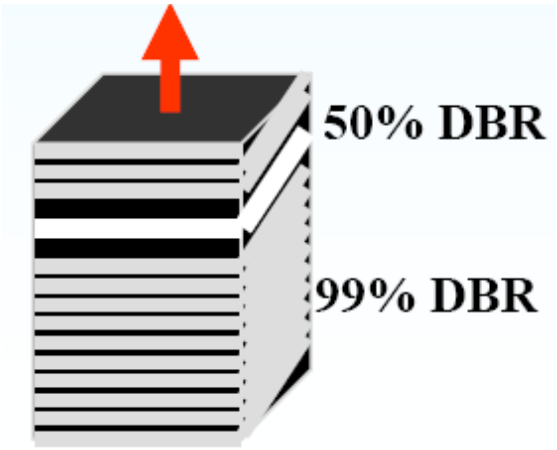
B + Phosphor(磷光体) LED

~40 Mb/s



R+G+B LED

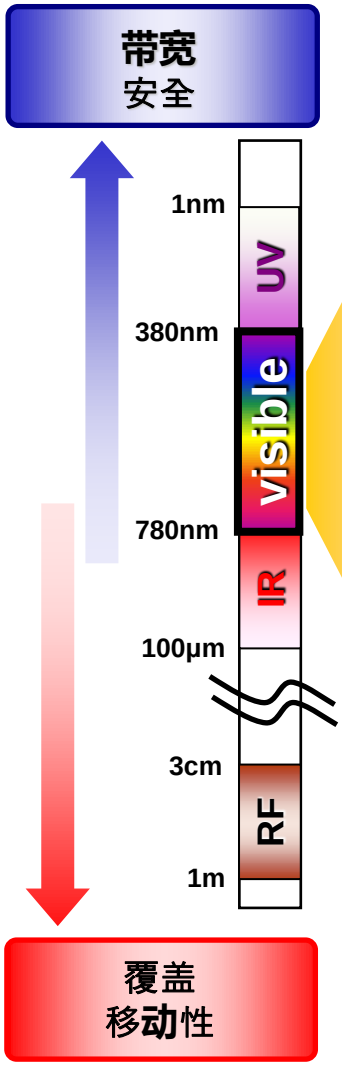
~100 Mb/s



RCLED
(共振腔LED)

~500 Mb/s

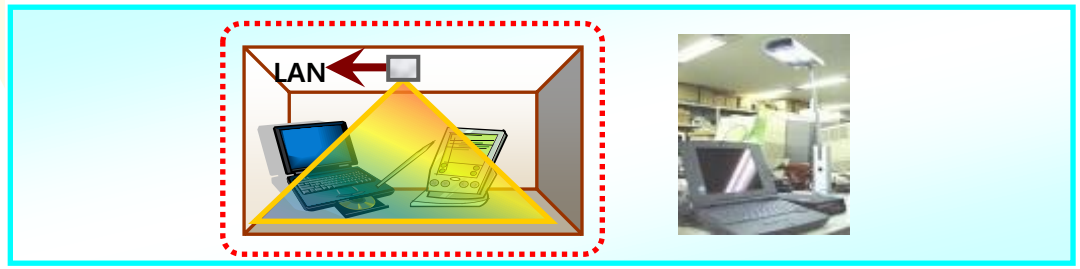
VLC 应用



Peripheral Interface (外围接口)

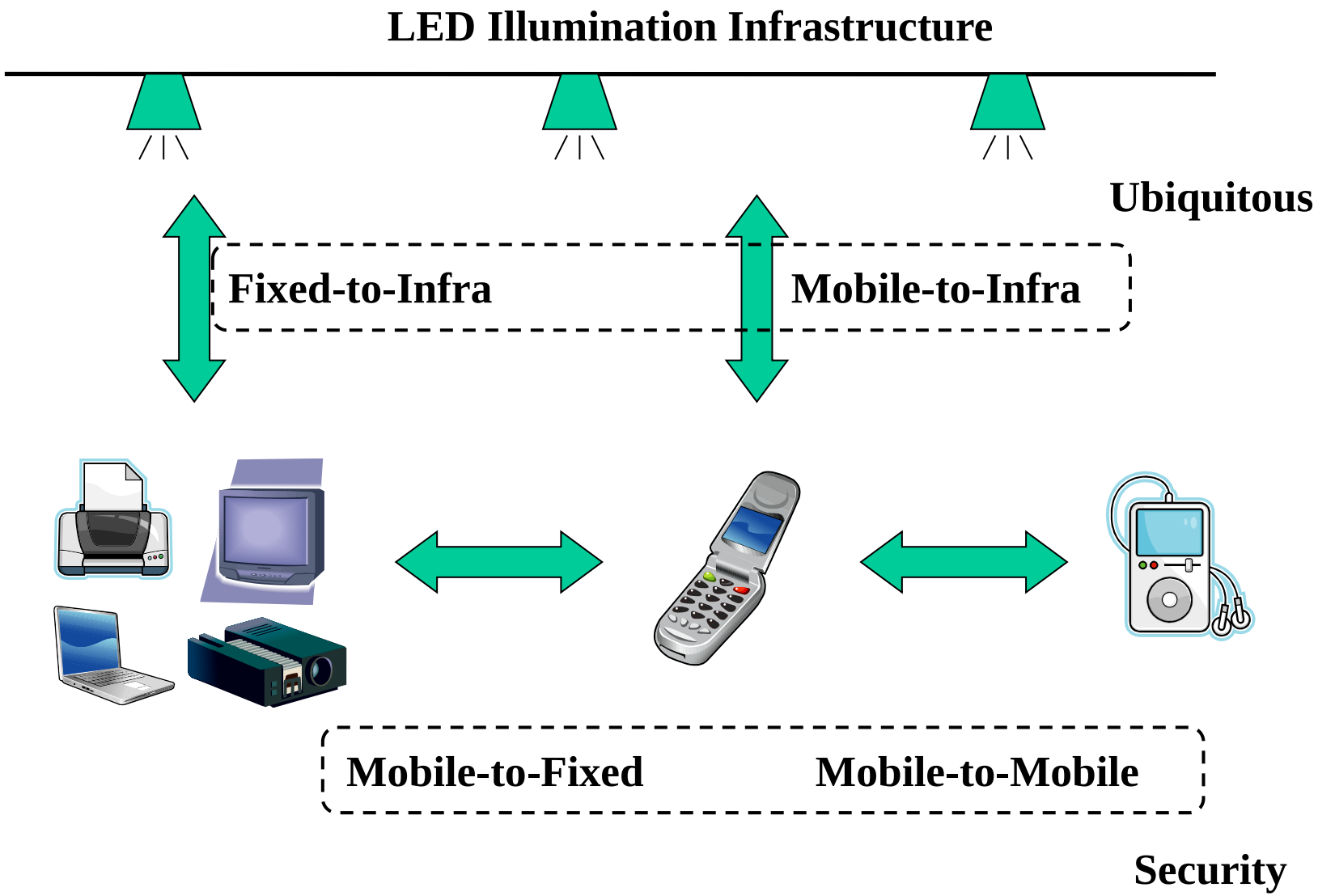
信息广播

射频禁止



可见光局域网

室内应用

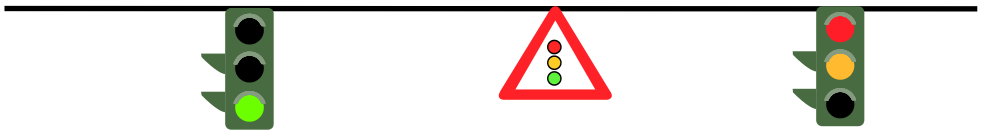

LED Illumination Infrastructure
Ubiquitous
Fixed-to-Infra
Mobile-to-Infra
Mobile-to-Fixed
Mobile-to-Mobile
Security

要求（室内应用）

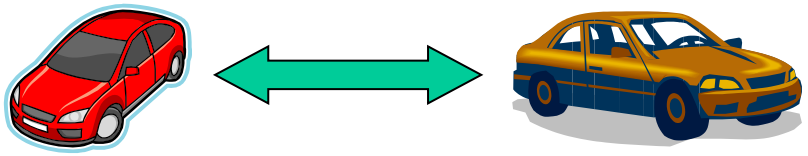
	Mobile to Mobile	Mobile to Fixed	Mobile to Infra	Fixed to Infra
Link	Bi-direction	Bi-direction	Bi or Uni	Bi or Uni
Reach	~1m	~1m	~3m	~3m
Rate	~100M	~100M	~10M	~10M
Application	Contents sharing	File transfer Video streaming M-commerce(移动商务)	Indoor navigation LBS(基于位置的服务) Networked robot (网络机器人)	Data broadcast
Alternative	IrDA, Bluetooth, UWB	IrDA, Bluetooth, UWB		WLAN

室外应用

Traffic control Infrastructure



Vehicle-to-Infra



Vehicle-to-Vehicle

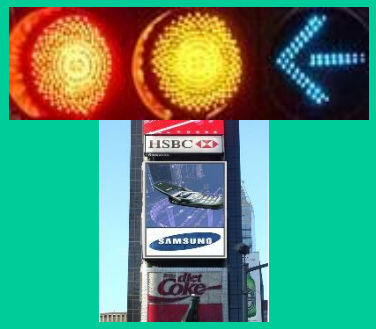
Outdoor advertising

VLC应用发展

LED penetration

Mobile Display

Sign ITS



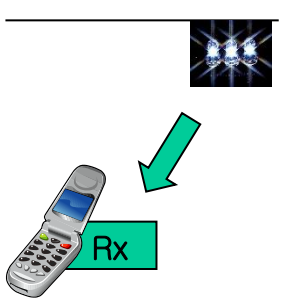
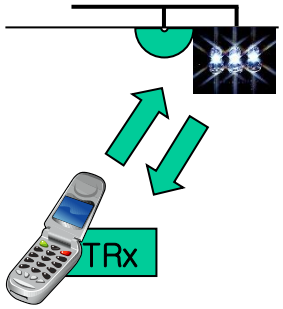
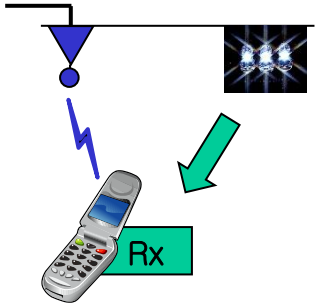
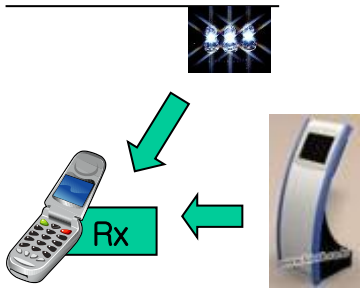
Illumination

100M Indoor

10M Outdoor

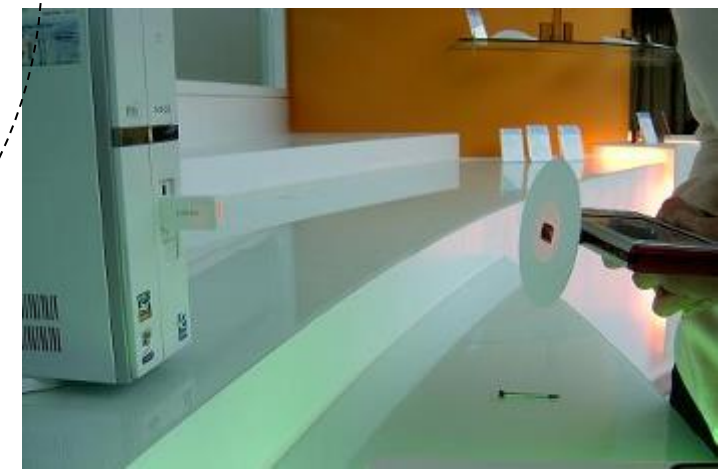
10M Indoor

室內导航方案

	Uni-direction	Bi-direction	Hybrid	Hot spot
Link				
Rate	▪ Down : ~10k	▪ Down : ~10M ▪ Up : ~100M	▪ Down : ~10k ▪ Up : ~10M	▪ Down(light) : ~10k ▪ Down(HS) : ~100M
Infra	▪ Lighting with optical ID	▪ Lighting with optical ID ▪ Receiver ▪ In-building network ▪ Routing server	▪ Lighting with optical ID ▪ RF access point ▪ In-building network ▪ Routing server	▪ Lighting with optical ID ▪ Hot spot
Mobile	▪ Receiver ▪ Large storage ▪ Map info ▪ Routing software	▪ Receiver ▪ Transmitter	▪ Receiver ▪ RF connectivity	▪ Receiver ▪ Large storage ▪ Routing software
Other service		LBS Ad-hoc connection	LBS	

高速高安全连接

What You See Is What You Send (WYSIWYS)



E-Contents Vending Machine

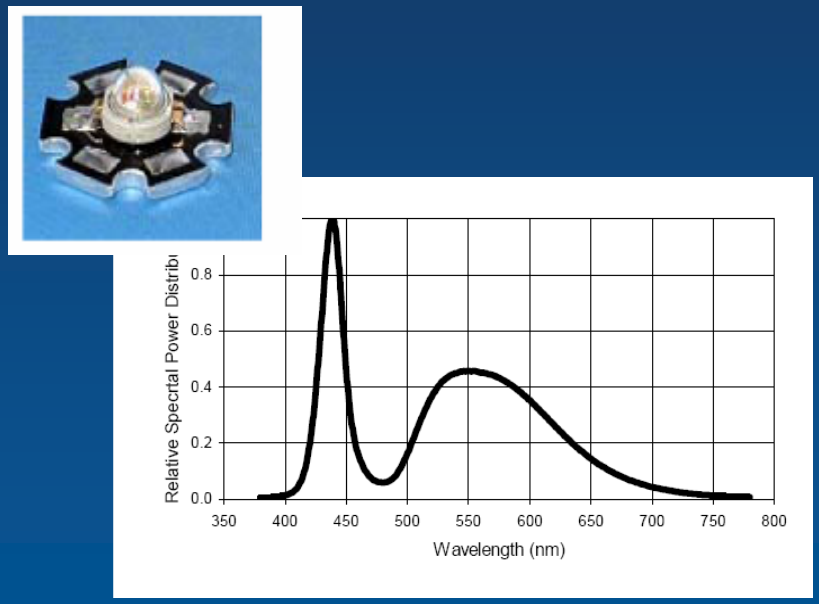
（电子内容物自动售货机）

第二部分

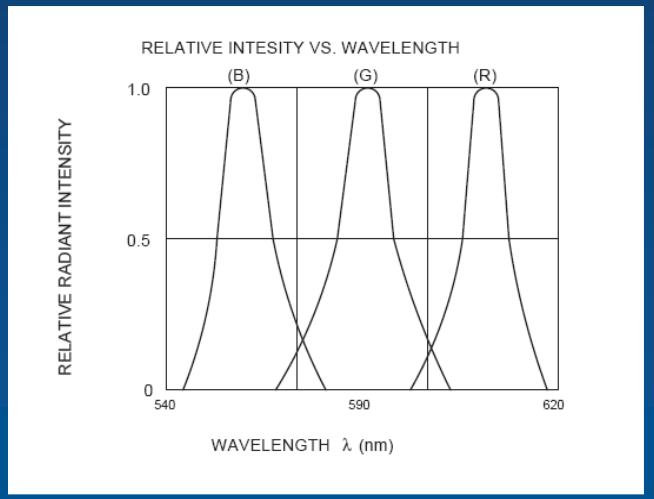
- 可见光通信
  - 发射机
  - 信道
  - 接收机
- 技术挑战
  - 更高的带宽
  - 实现移动性和可靠性

VLC源

- 蓝色LED和磷光体
  - 低成本
  - 磷光体限制了带宽
  - 调制会引起色变
- RGB三重态
  - 更高的成本
  - 可能更高的带宽
  - 波分复用的潜力
  - 无色移调制



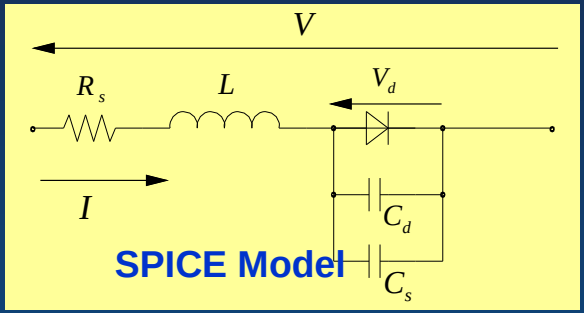
Single chip LED spectrum



RGB LED spectrum

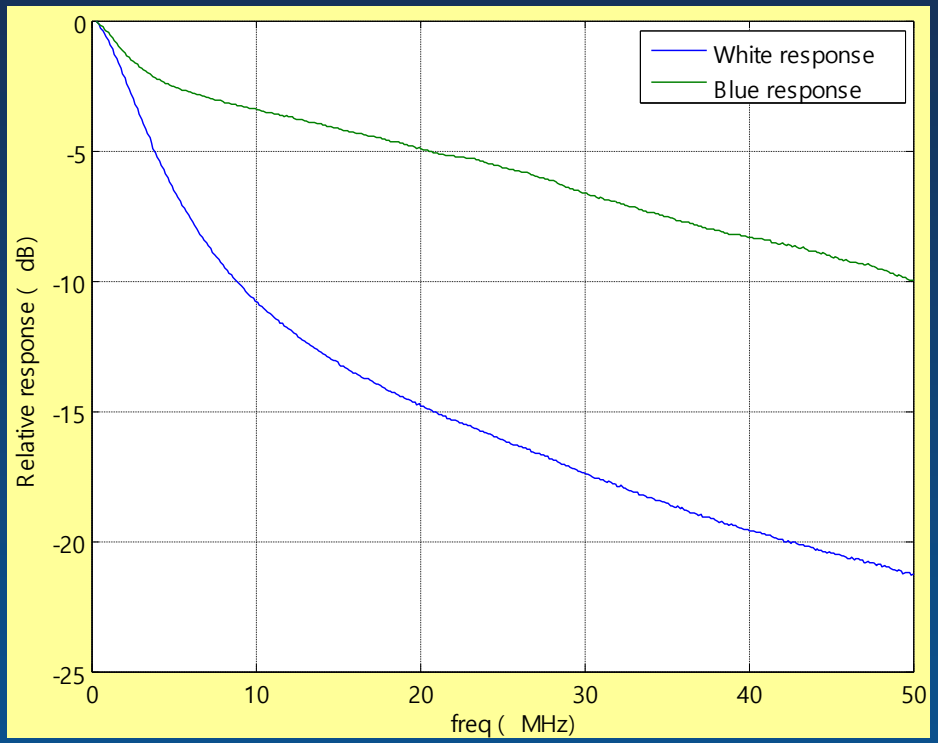
LED调制

- 光电响应



Luxeon LED

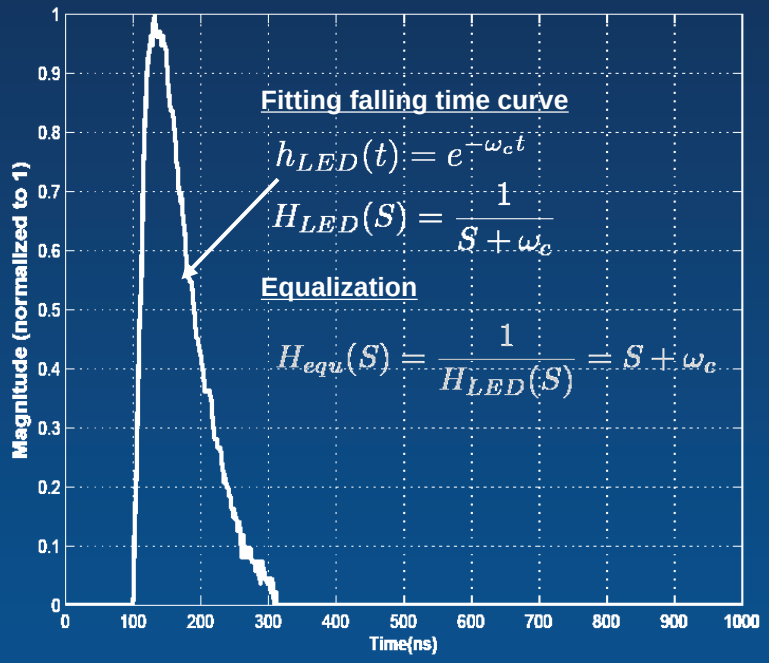
R_s = 0.9727 Ω
L = 33.342 nH
C_s = 2.8 nF
C_d = 2.567 nF
tt = 1.09 ns



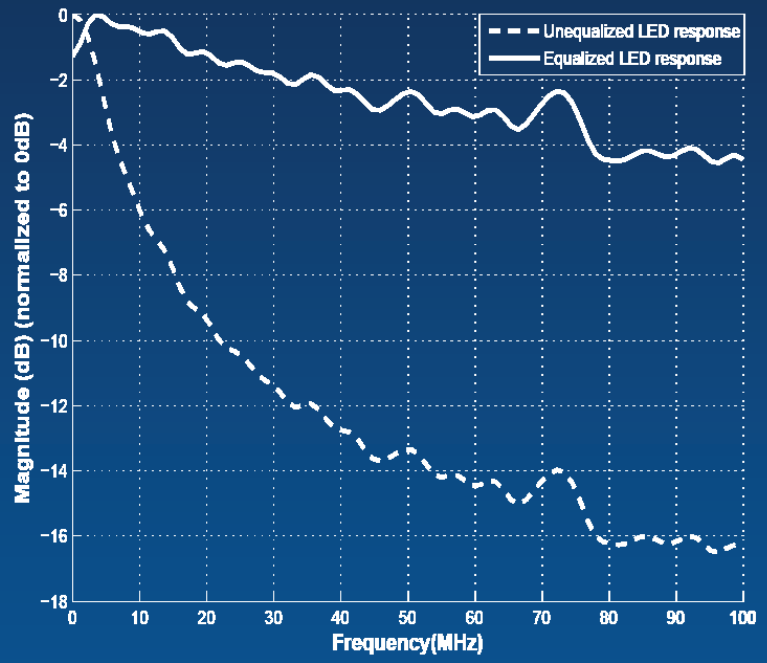
Measured LED small-signal bandwidth

改善信道响应

- 接收机均衡



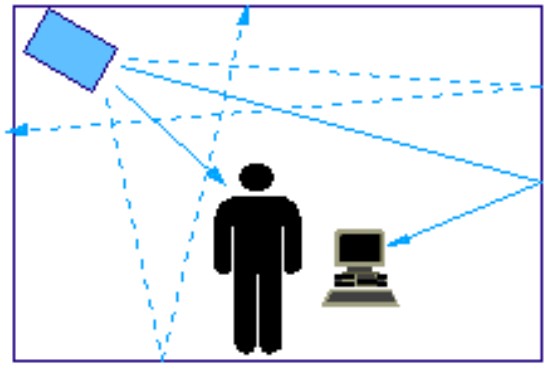
Measured LED impulse response



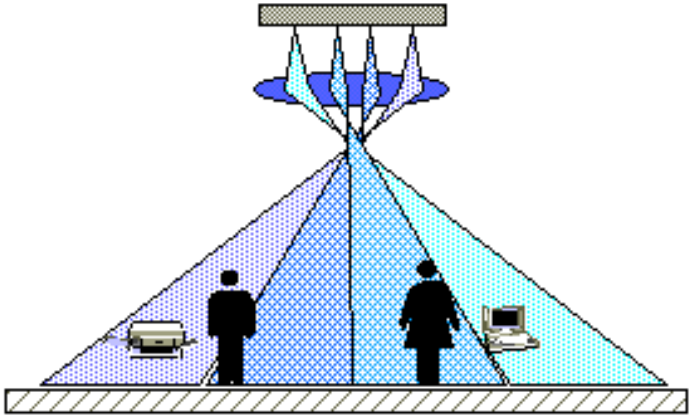
Improved LED transmission BW

信道建模

- 两条传播路径:
- 视线（LOS）：使用LED阵列的照明模式计算的强路径
- 漫反射(漫射): 假设房间相当于一个积分球
- 计算室内每个点的信道冲激响应

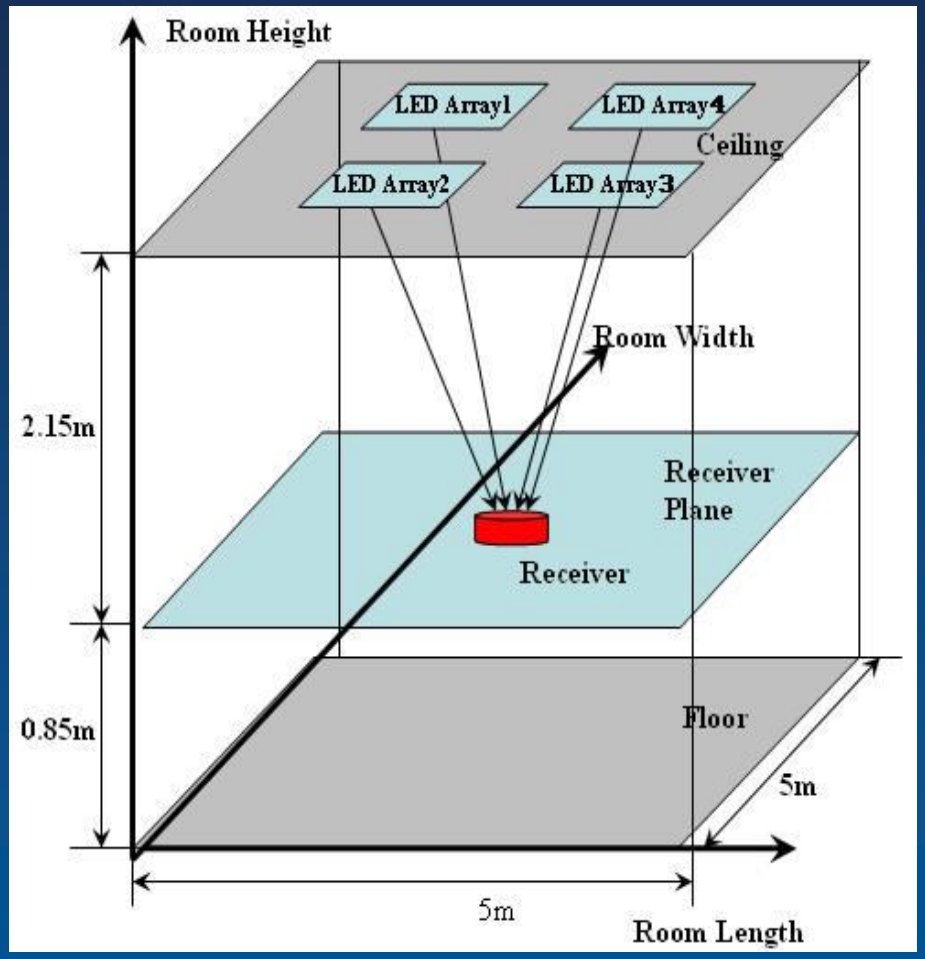


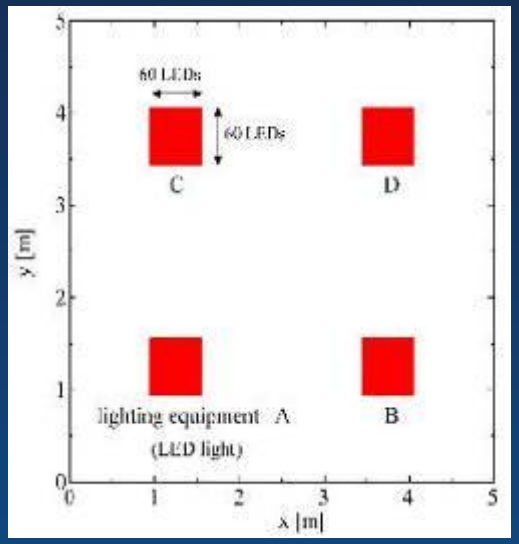
Diffuse channels

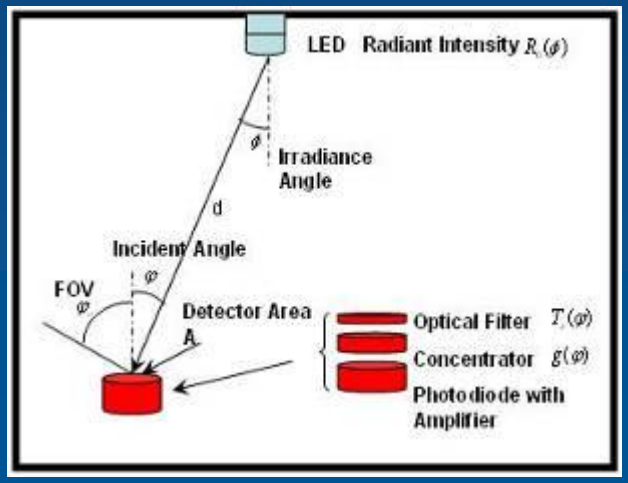


Line of sight channels

VLC建模


Room Height
LED Array1
LED Array4
Ceiling
LED Array2
LED Array3
Room Width
2.15m
Receiver Plane
Receiver
0.85m
Floor
5m
5m
Room Length


60 LEDs
60 LEDs
C
D
y [m]
lighting equipment A
(LED light)
B
x [m]

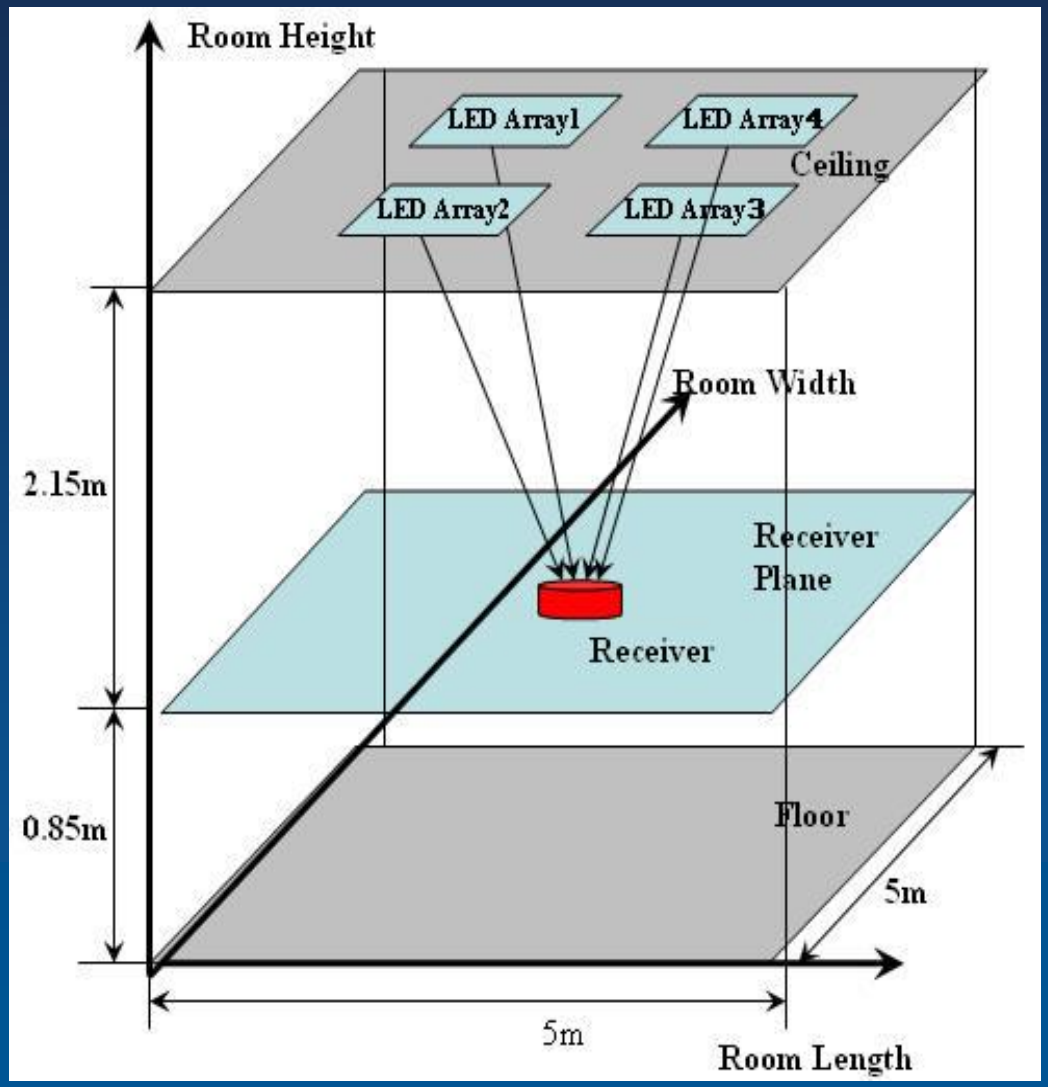

LED Radiant Intensity $R_o(\phi)$
Irradiance Angle
d
Incident Angle
FOV
Detector Area A
Optical Filter $T(\varphi)$
Concentrator $g(\varphi)$
Photodiode with Amplifier

未来发展：光MIMO

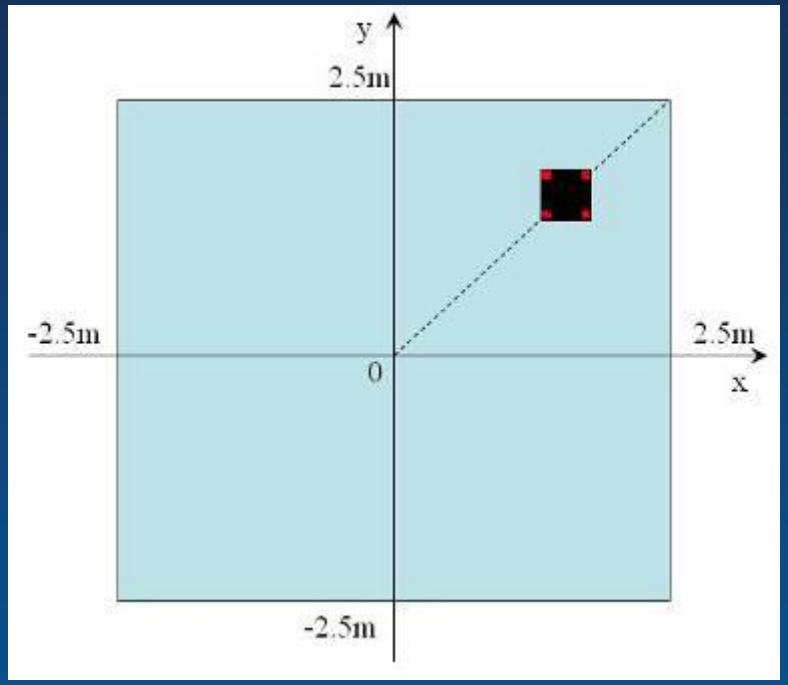
- 射频MIMO
- 散射提供可逆的H矩阵和去相关（容量增益）
- 小天线难以形成辐射方向图

- 光MIMO
- 无去相关
- 系统实现可逆H矩阵及几何设计
- 简单的低成本元件（透镜）可以提供高方向性和/或复杂的波束成形

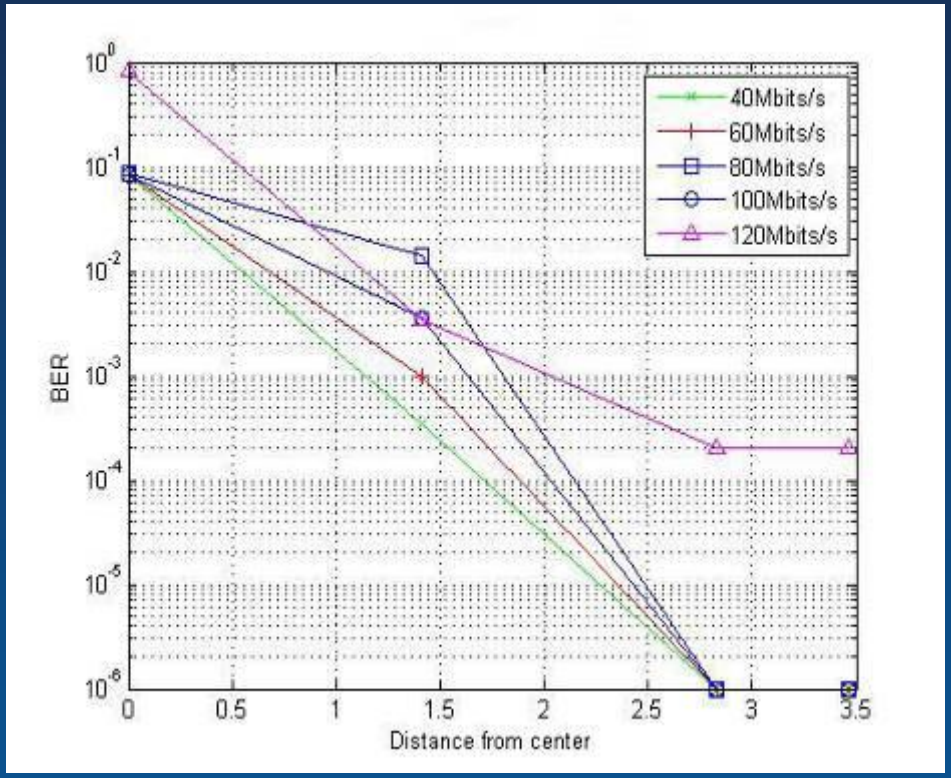
MIMO-VLC：仿真系统



MIMO-VLC：初步结果



Position of the receiver



聚合数据速率与信道数和信道速率成线性比例

作业：

- 1、VLC的一般特征有哪些?
- 2、VLC信道的两条传播路径是什么?