Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Modulation Issues of Visible Light Communication]

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Re: []

Abstract: [The overview of the visible light communication (VLC) and research issues related in modulation techniques are presented in this document.]

Purpose: [Contribution to IEEE 802.15 SG-VLC]

Modulation Issues of Visible Light Communication

2008. 05. 14

Samsung Electronics

Outline

- Introduction
- VLC characteristics
- VLC modulation techniques
- Summary

Introduction

- **VLC (Visible Light Communication)**

  : **New communication technology using "Visible Light".**

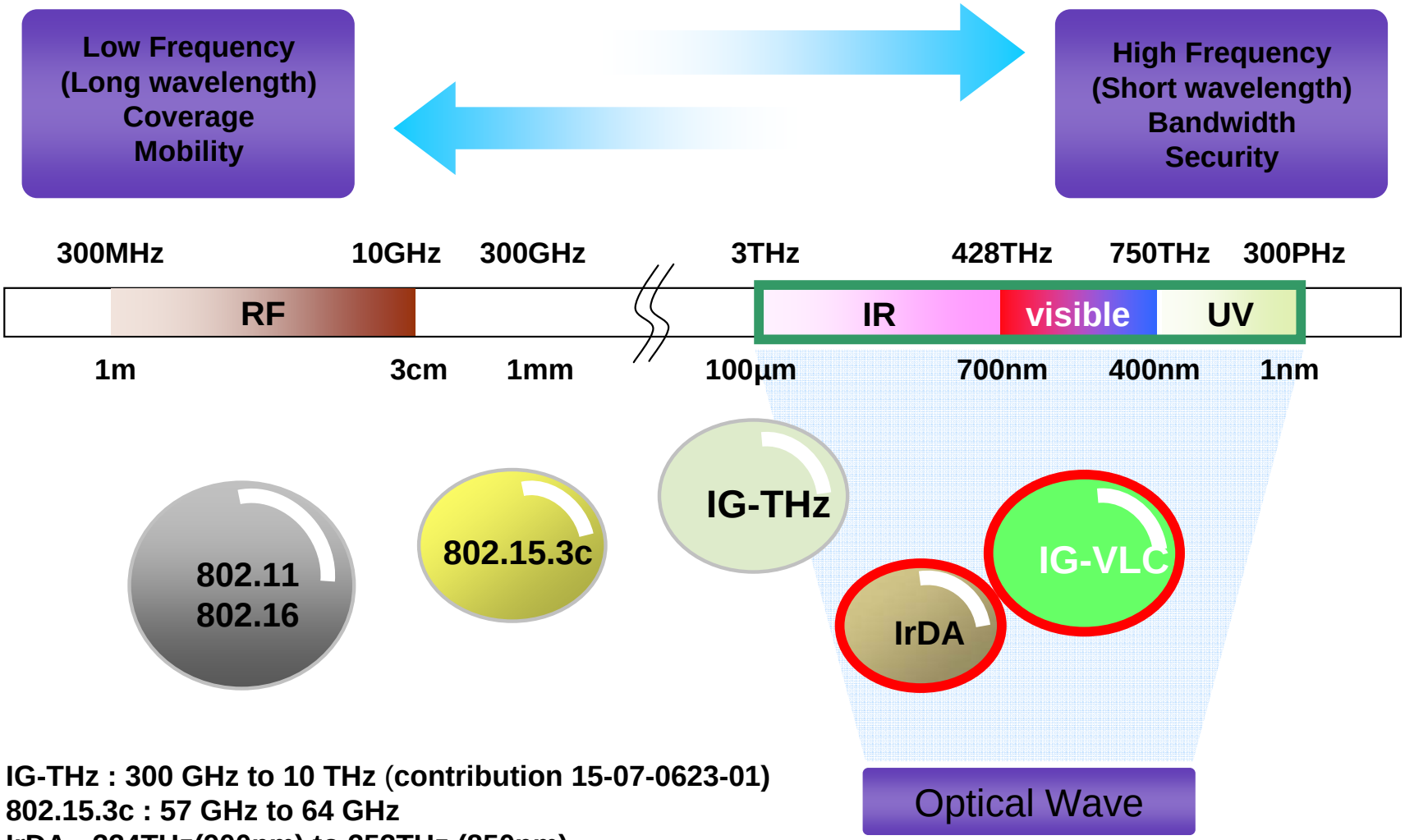
- **Visible Light**

  : **Wavelength between ~400nm (750THz) and ~700nm (428THz)**

  cf. IrDA Communication : from 850nm (353THz) to 900nm (334THz)

- **General Characteristic**
  - Visibility : Aesthetically pleasing
  - Security : What You See Is What You Send.
  - Health : Harmless for human body
  - Unregulated : No regulation in optical frequency

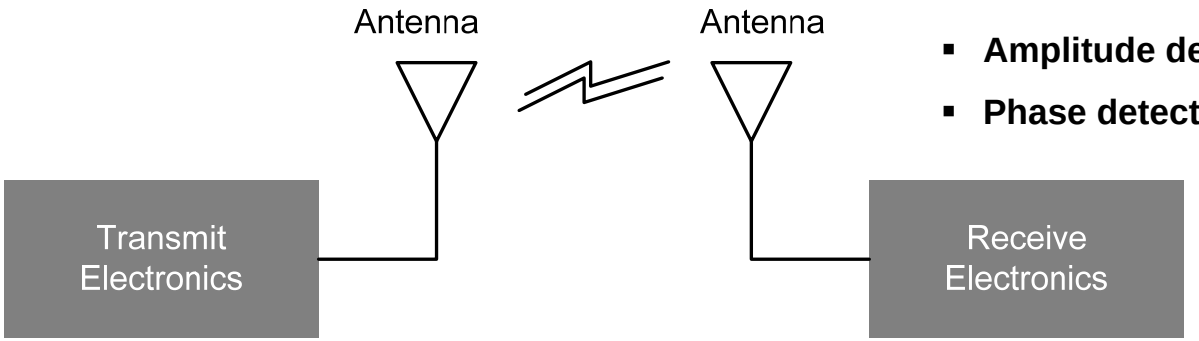
Frequency band of VLC



- IG-THz : 300 GHz to 10 THz (contribution 15-07-0623-01)
- 802.15.3c : 57 GHz to 64 GHz
- IrDA : 334THz(900nm) to 353THz (850nm)

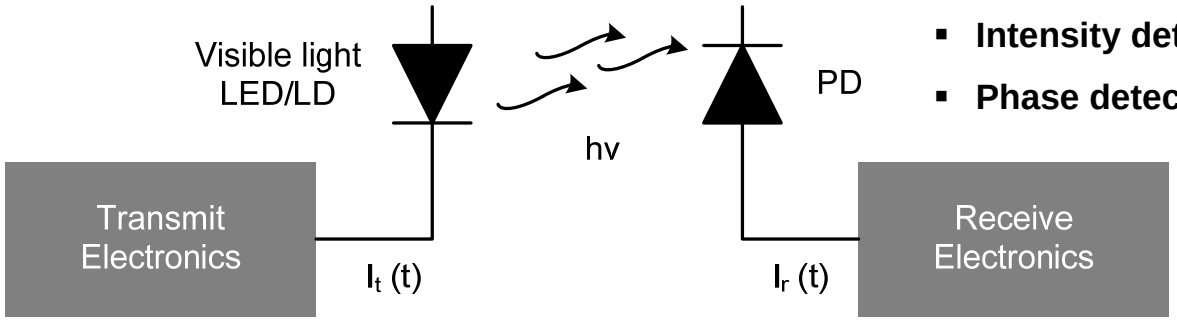
Schematics of RF comm. and VLC

- **Visible Light Communications**
  - LED emits incoherent light over a wide spectrum.
  - Photodiode is linear over a wide input range.



- **Amplitude detection**
- **Phase detection is possible.**

- Schematics of RF communication -



- **Intensity detection (IM/DD)**
- **Phase detection is impossible.**

- Schematics of VLC -

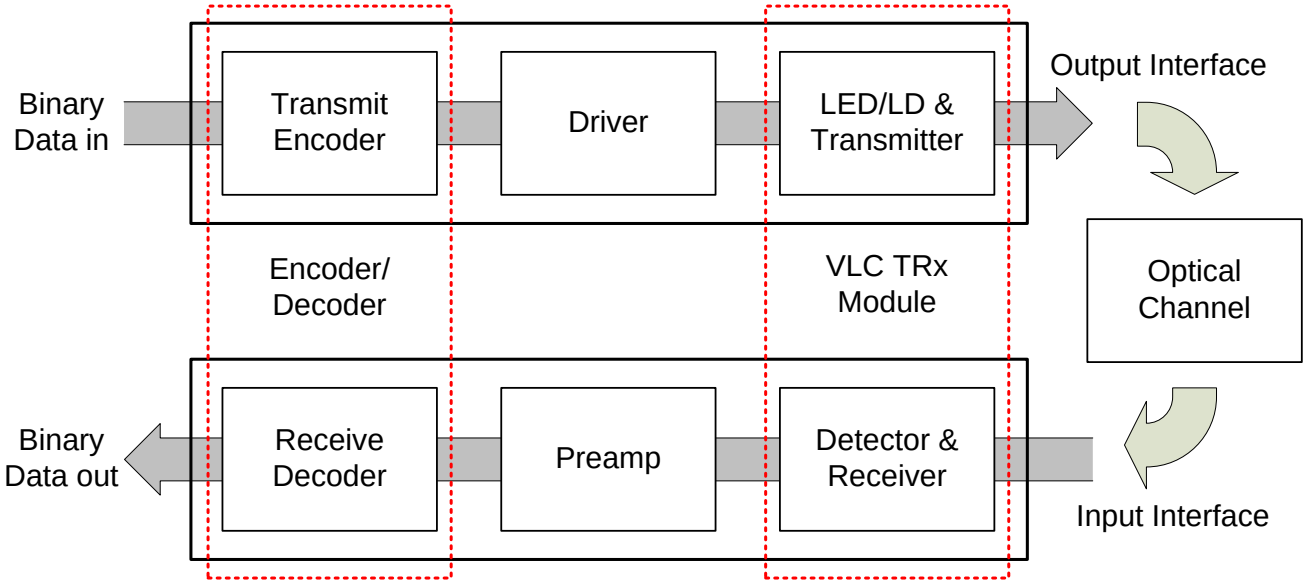
Characteristics of VLC

Visible Light Communications

- RF comm. has frequency bandwidth limitation.
  - The data rate limitation and complex modulation format
- But, VLC is no frequency limitation. Baseband direct transmission can be enough possible.
- Ambient Noise Source is serious.
  - Sunlight, fluorescent, incandescent light etc.
- In case of using as lightening, the brightness should be seriously considered.
- Therefore, suitable modulation scheme should be required.

VLC modulation

- **LED can have various modulation methods.**
  - Digital modulation methods
    - ASK, FSK, PSK, QAM, OFDM etc.
  - Digital baseband modulation or line coding
    - Unipolar / Bipolar, NRZ / RZ, Manchester code, AMI (alternative mark inversion) code
  - Pulse modulation methods
    - PCM, PWM, PAM, PPM etc.



Classification of Modulation Method

Single channel dimension : RF modulation dependent

RF based Technology, Optical device : Just transmission medium

- Nakagawa Lab. : OOK (NRZ, RZ), PPM, I-PPM, SC-PPM, SC-I-PPM, SC-FSK, SC-PSK, PAM, PWM
- IU-Bremen : QPSK based OFDM
- Univ. of Oxford : NRZ, Manchester code, RZ, PPM, PAM
- Samsung Electronics : NRZ, 8B/10B code (DC-balanced data coding)

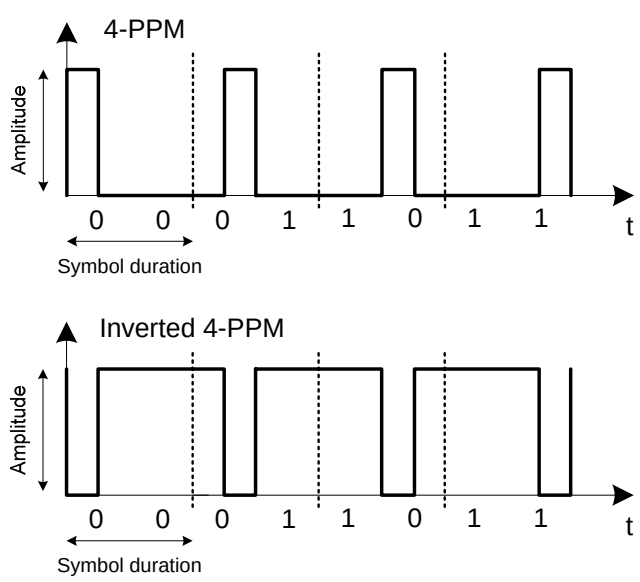
Multi-channel approach : Optical device dependent

Optical device based Technology : Multiplexing

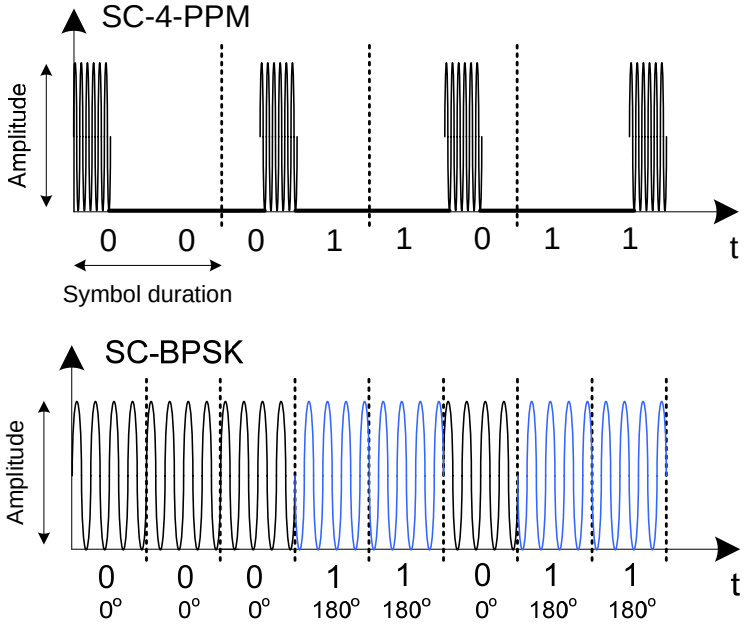
- Univ. of Oxford : Optical MIMO
- Samsung Electronics : Wavelength Division Multiplexing (WDM)

Single channel dimension

- **PPM / I-PPM**
  - PPM expresses the data with positioning.
  - I-PPM : Yields higher than conventional PPM. The transmitted power is improved.
  - Both of them are concentrated in the DC and low frequency bands range.
- **SC-PPM, I-PPM, PSK, FSK**
  - This shifts the power spectrum of the signal to higher frequency band



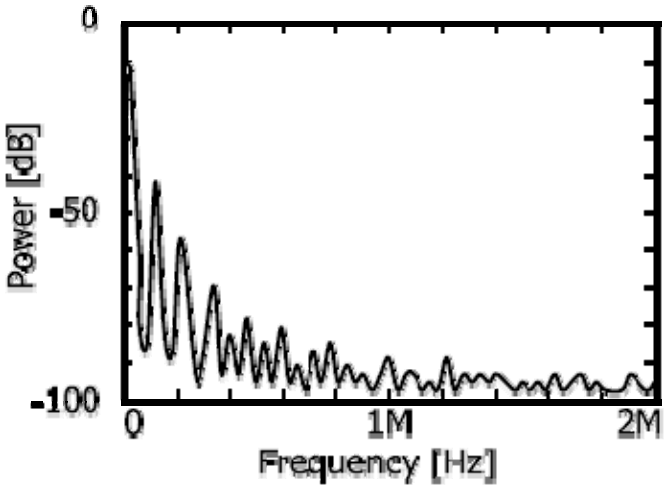
[Pulse pattern examples of PPM or I-PPM]



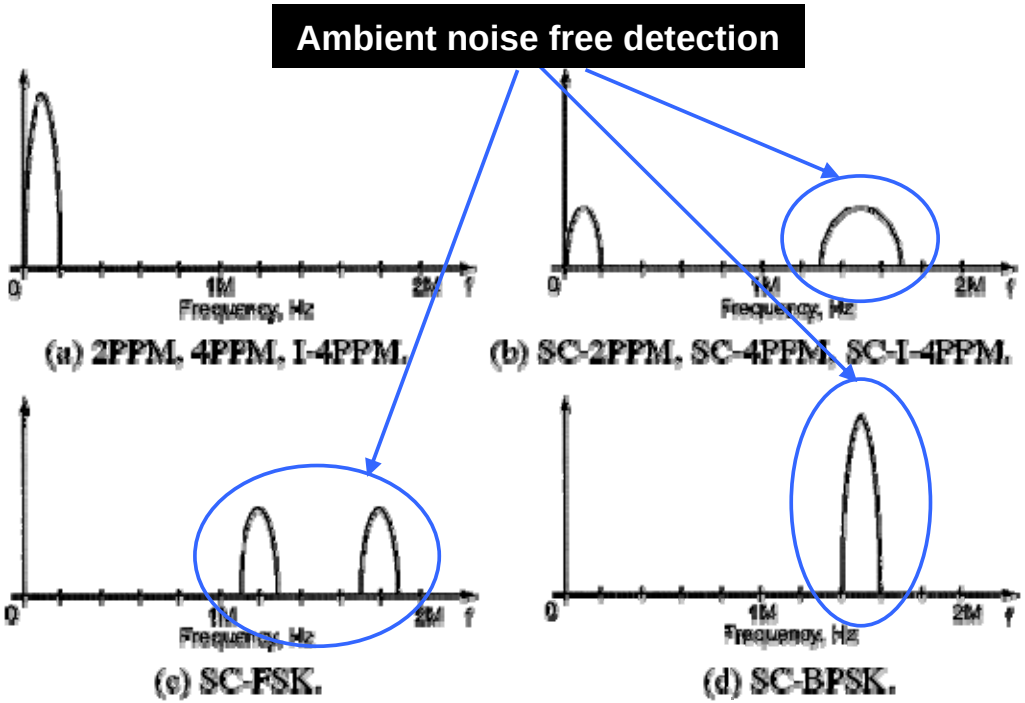
Citation: H. Sugiyama et al., IEICE Trans. Comm. Vol. E89-B, No. 12, pp. 3393-3400, Dec. 2006.

Single channel – Spectrum Analysis (1)

- **Flourescent lamp**
  - From DC to several hundreds of kHz
  - SC modulation : DC noise free operation is possible.
    - Because, the data signal is transferred near the SC.



[Flourescent noise spectrum]



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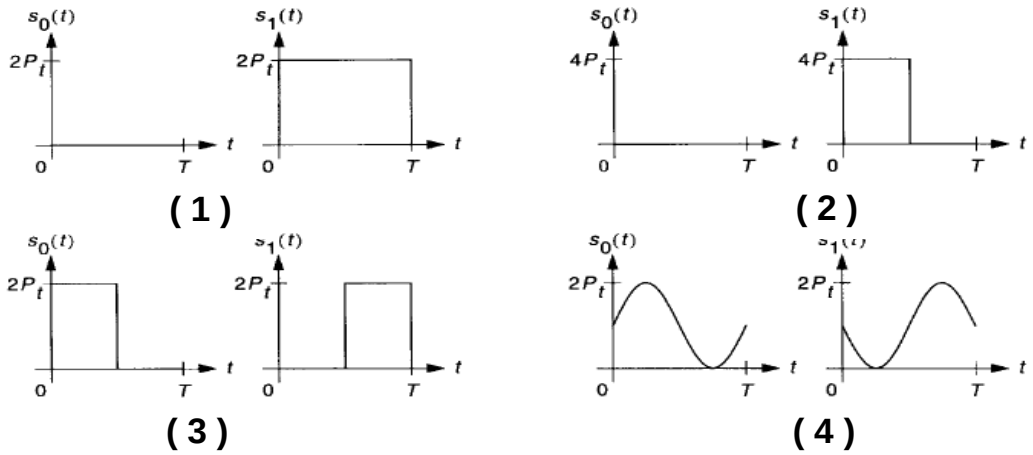
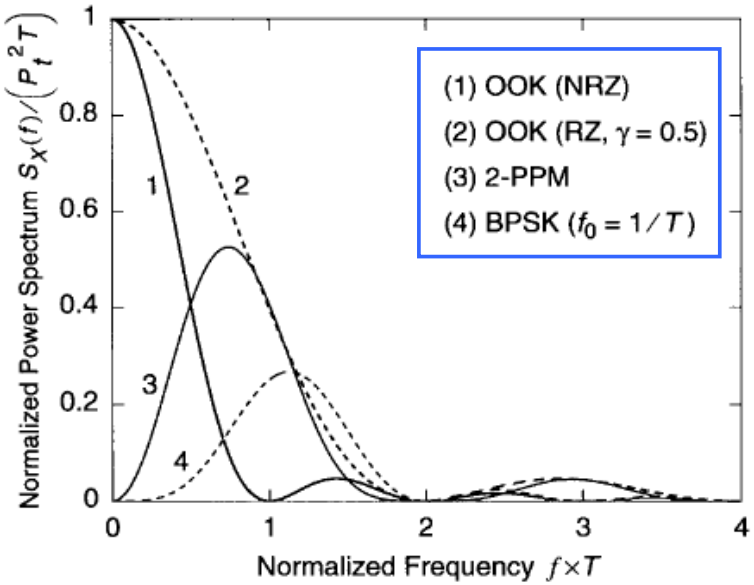
Single channel – Spectrum Analysis (2)

- **Data & Noise spectrum**



[Pulse patterns]

- baseband modulation has power density near DC level.
- It can be helped to use SC.



[Data spectrum]

Multi-channel approach

- **LED Array**
  - the bandwidth can be enough expanded. Because, each LED bandwidth is added proportionally.
  - However, multiple parallel driving circuit should be required.
  - Wavelength division multiplexing (WDM) transmission
    - Red-Green-Blue Channel (Color multiplexing)

Summary

- **VLC modulation issues**
  - Single channel dimension
    - RF technology use is possible. However, physical hurdle is existed due to the bandwidths of optical devices used.
  - Multi-channel approach
    - Simple but, a lot of optical devices is used and each driver circuit is needed.
- **The technical hurdles**
  - Ambient noise avoidance technique
  - High speed operation technique
  - Constant brightness

Thank You !!!