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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]

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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**

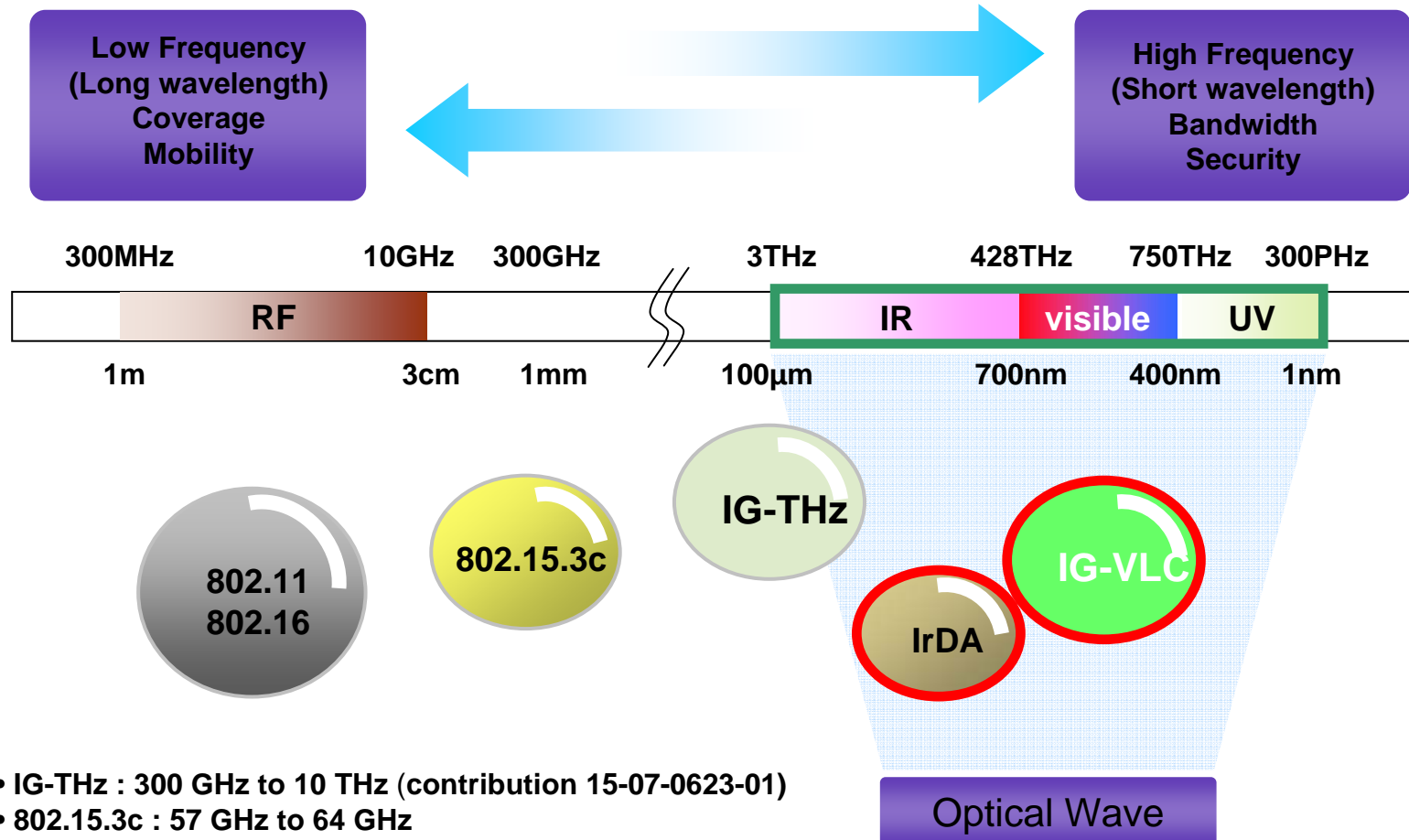
 - : **Wavelength between ~400nm (750THz) and ~700nm (428THz)**

 - 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

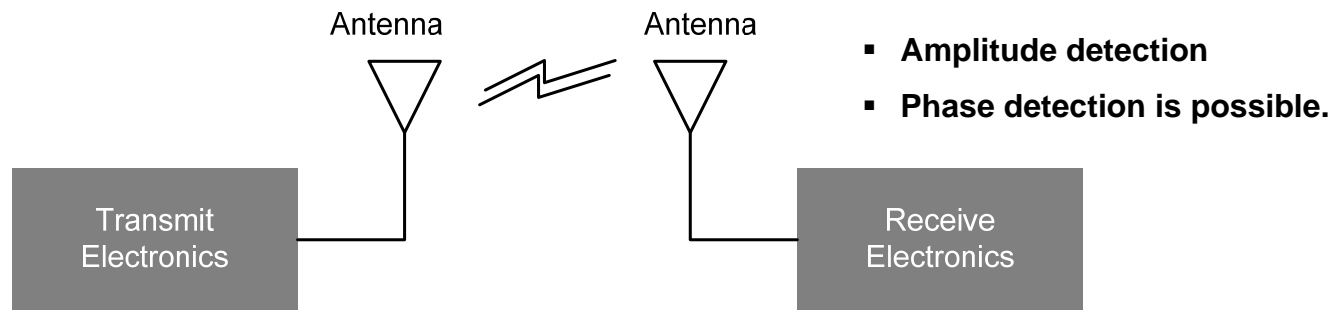


- IG-THz : 300 GHz to 10 THz (contribution 15-07-0623-01)
- 802.15.3c : 57 GHz to 64 GHz
- IrDA : 334THz(900nm) to 353THz (850nm)

Schematics of RF comm. and VLC

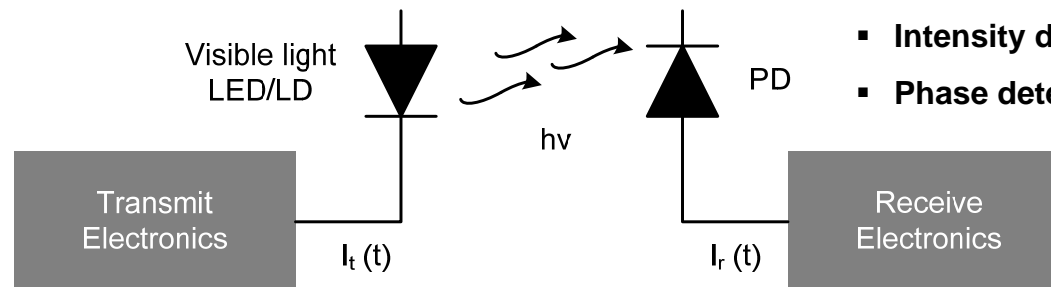
Visible Light Communications

- 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

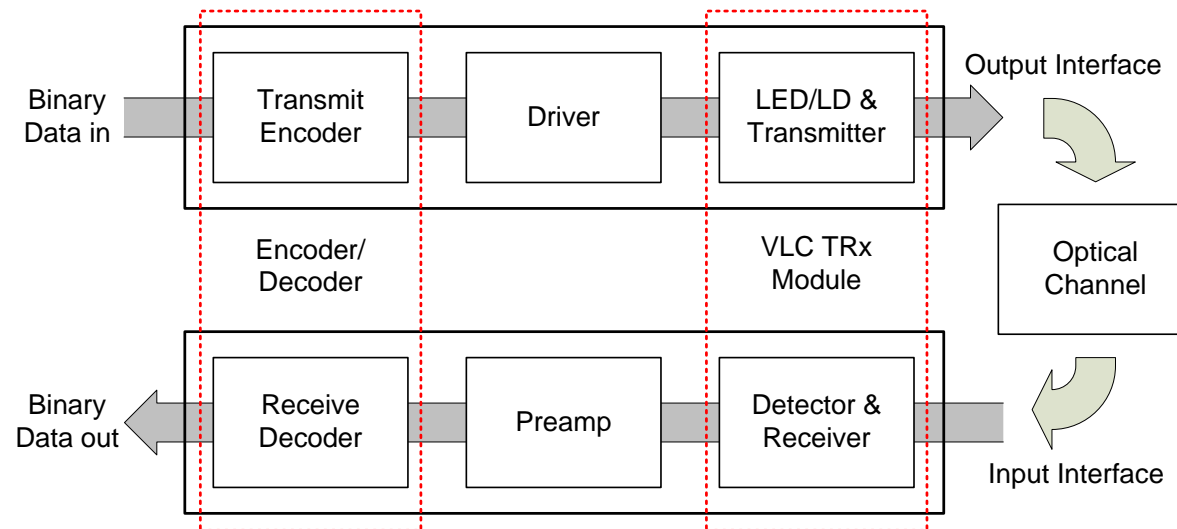
● Visible Light Communications

- 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, luminescent light etc.
- In case of using as lightening, the brightness should be seriously considered.
- Therefore, various 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)

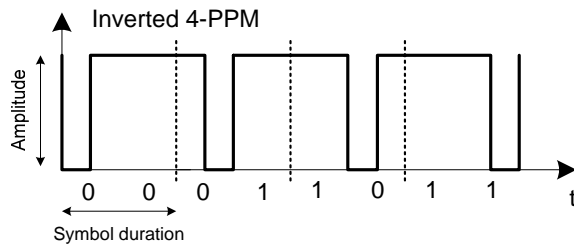
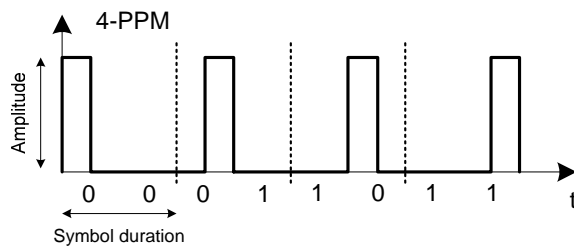
Single channel dimension

● PPM / I-PPM

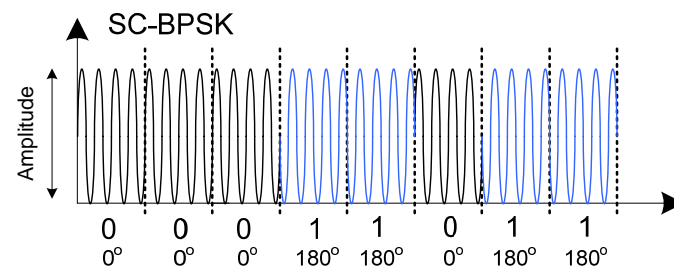
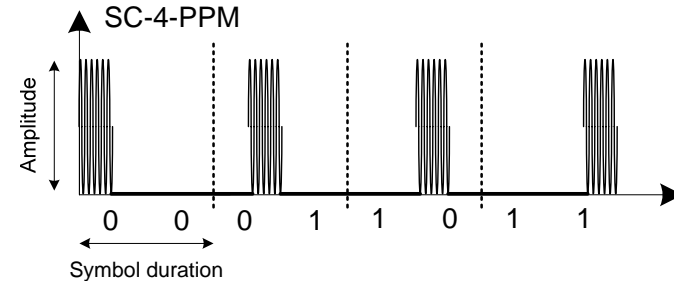
- PPM expresses the data as positioning.
- I-PPM : Yields higher than conventional PPM. The transmitted power is improved.
- Both of them are concentrated in the DC and low frequency bands range.

● 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]

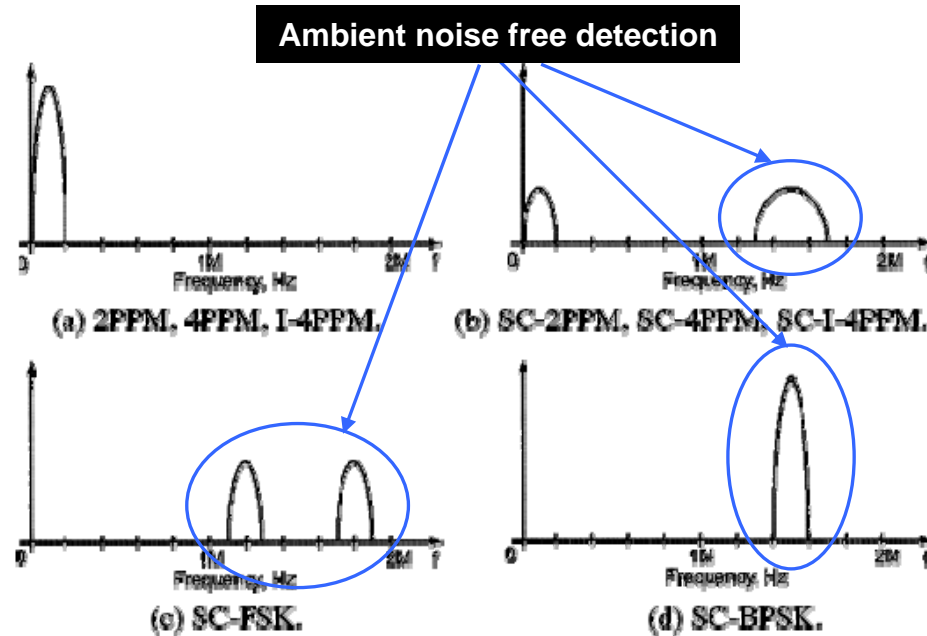
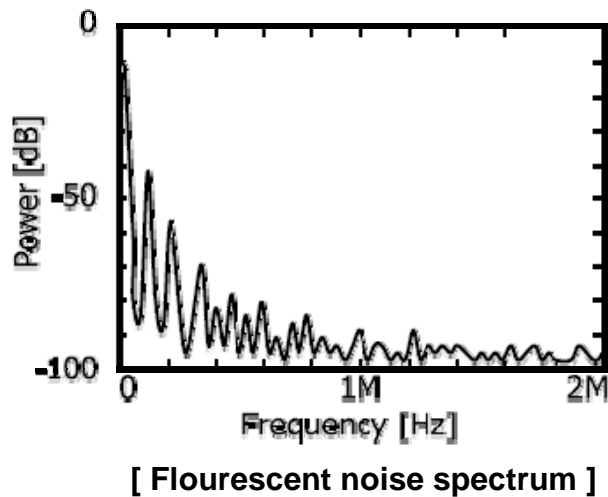


Citation: H. Sugiyama et al., IEICE Trans. Comm. Vol. E89-B, No. 12, pp. 3393-3400, Dec. 2006.

Single channel – Spectrum Analysis (1)

● Flourescent lamp

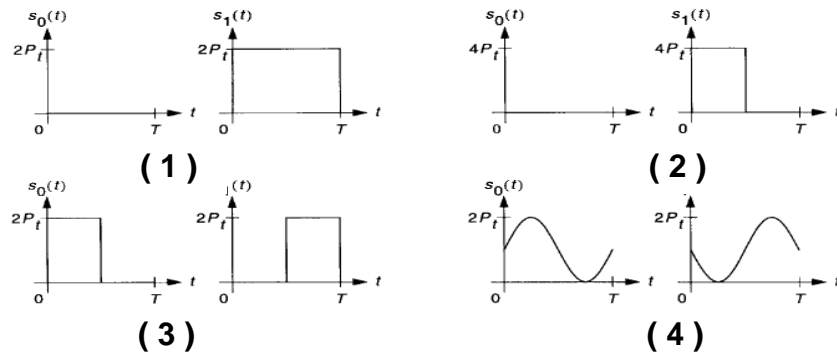
- From DC to several hundreds of kHz
- SC modulation : DC noise free operation is possible.
 - Because, the data signal is transferred near the SC.



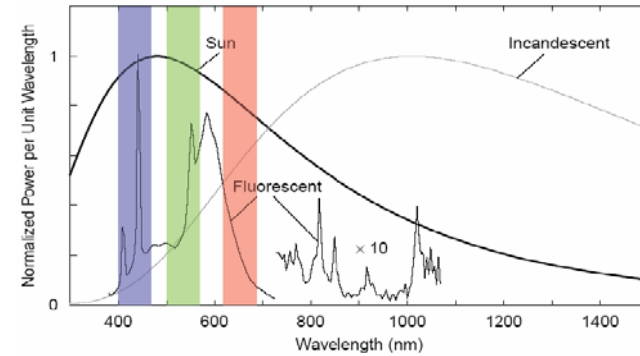
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Single channel – Spectrum Analysis (2)

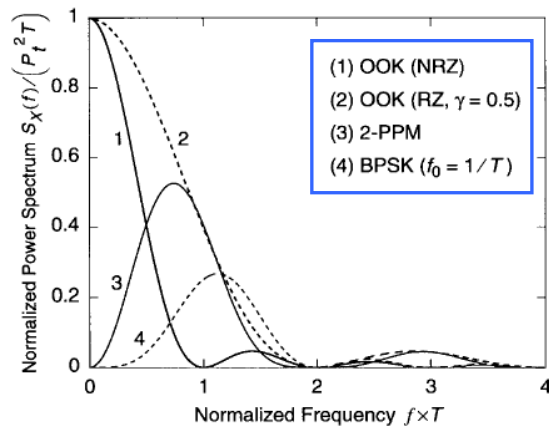
● Data & Noise spectrum



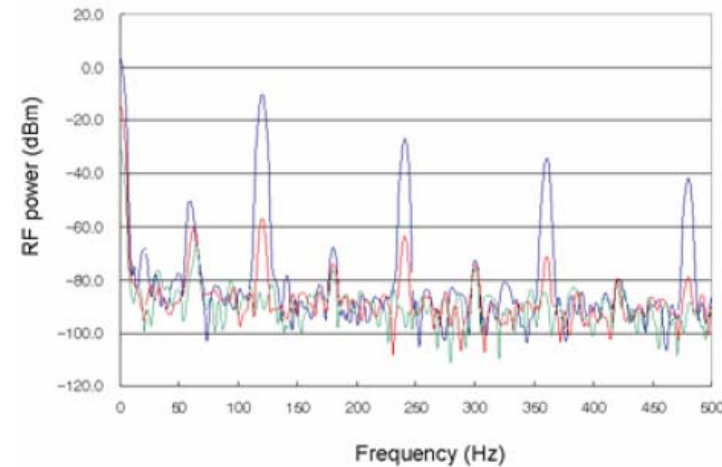
[Pulse patterns]



[Optical spectrum]



[Data spectrum]



[Noise spectrum]

Multi-channel approach

● LED Array

- Parallel driving circuit
- Multiple driving circuit is required.
- Wavelength division multiplexing (WDM) transmission
 - Red-Green-Blue Channel (Color multiplexing)
 - Optical MIMO
 - Bandwidth expansion possible by summation

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 solved technical hurdles

- Ambient noise avoidance technique

- High speed operation technique

- Constant brightness

Thank You !!!