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**Submission Title:** [Modulation Categorization of Visible Light Communication]

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**Re:** []

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

**Purpose:** [Contribution to IEEE 802.15 SG-VLC]

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# **Modulation Categorization of Visible Light Communication**

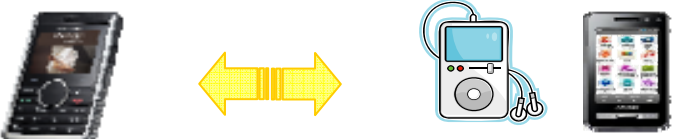
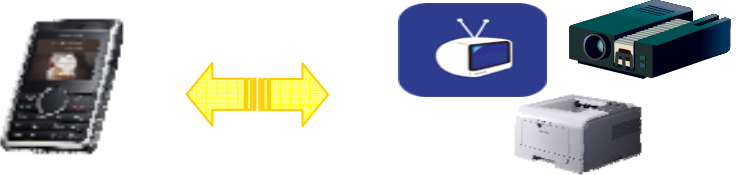
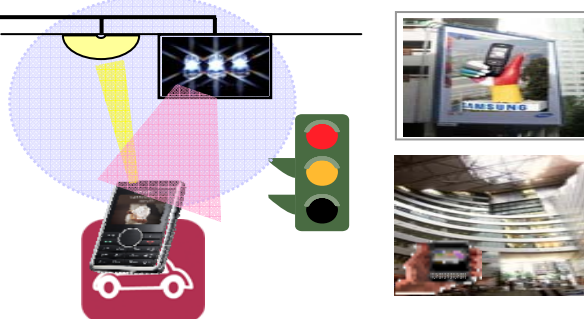
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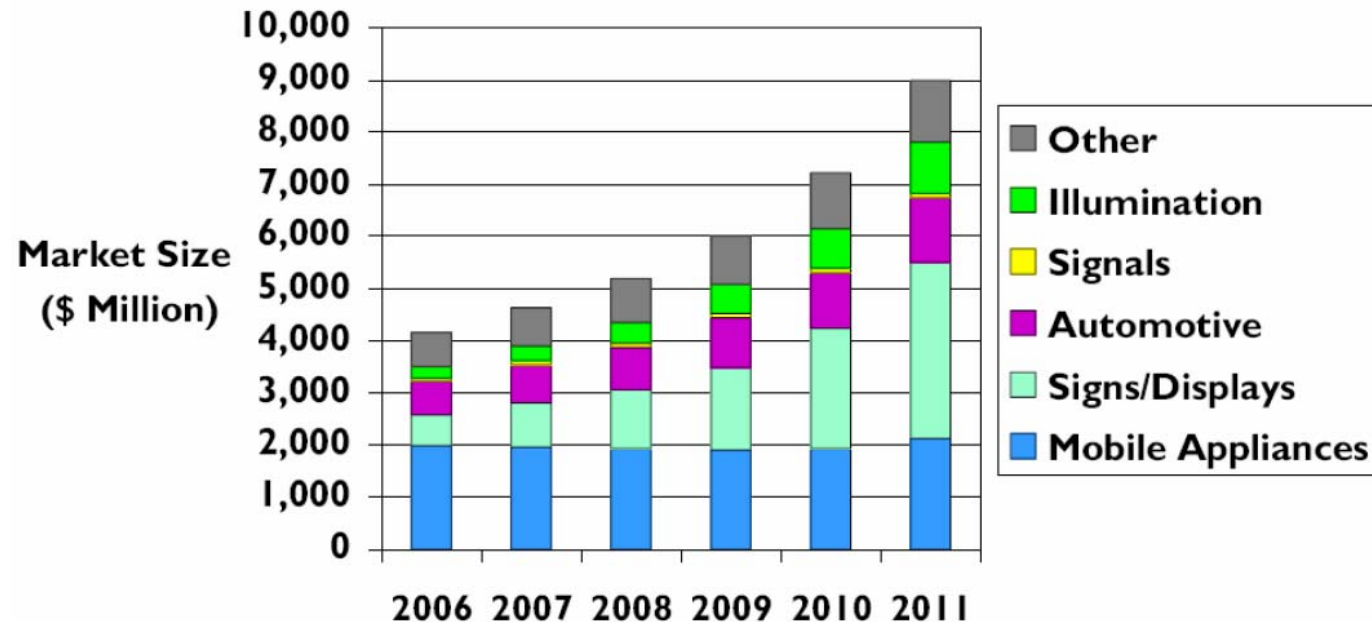
# Outline

- **Classification of VLC applications**
- **Modulation Issue of VLC Applications**
- **Original Function of LED**
- **Illumination and Communication Function  
of LED**
- **Summary**

# Classification of VLC Applications

	Application	Available Service	Major Function
<b>Mobile to Mobile</b>	 <p>Handheld device, Portable device</p>	<ul style="list-style-type: none"> <li>• Contents-sharing</li> <li>• Data transfer</li> </ul>	<b>Communication</b>
<b>Mobile To Fixed</b>	 <p>CE, Kiosk, Portable device, Handheld device</p>	<ul style="list-style-type: none"> <li>• File transfer</li> <li>• Video streaming</li> <li>• Remote Control</li> </ul>	
<b>Infra To Mobile</b>	 <p>CE Illuminator Sign-board Traffic Signal Portable device Handheld device</p>	<ul style="list-style-type: none"> <li>• Indoor Navigation</li> <li>• Information Broadcasting</li> </ul>	<b>Illumination and Communication</b>

# LED Infrastructure



- An indispensable element of the VLC
- Major function : illumination as a light source
- VLC applications related to LED infrastructure

# Modulation Issue of VLC Applications

- **Mobile-to-Mobile/Fixed**
  - Communication between portable or fixed devices
  - Modulation method required for only communication
  
- **Infra-to-Mobile**
  - Illumination function should be considered as well as communication function
  - New modulation method may be required.
  - Especially, the downlink of Infra-to-Mobile
  
- Different Modulation methods may be required as application classifications.

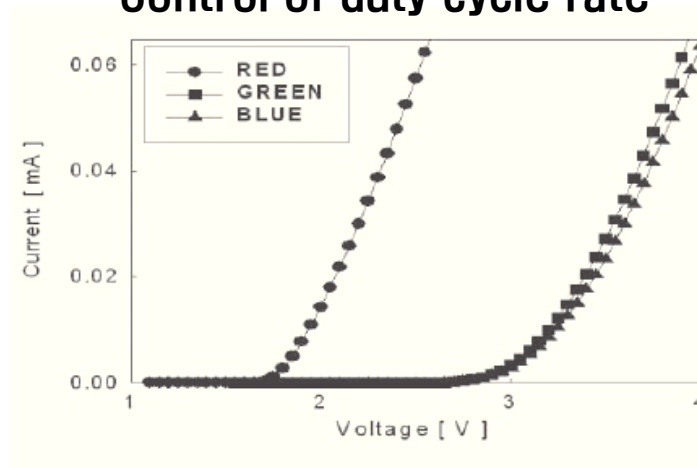
# Original Function of LED

- LED **brightness control**

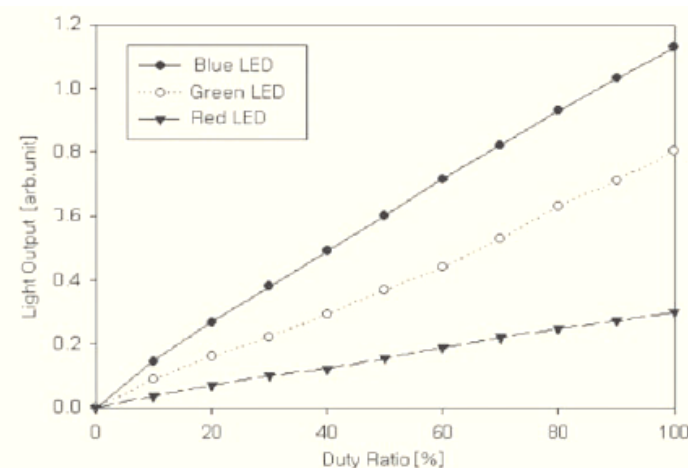
- Control of operating current causes severe temperate effect.
- The output variation is not linear.
- Also, the driving circuit is very complicated.

- **Current Solution**

- Use of PWM method in constant input voltage
- Control of duty cycle rate



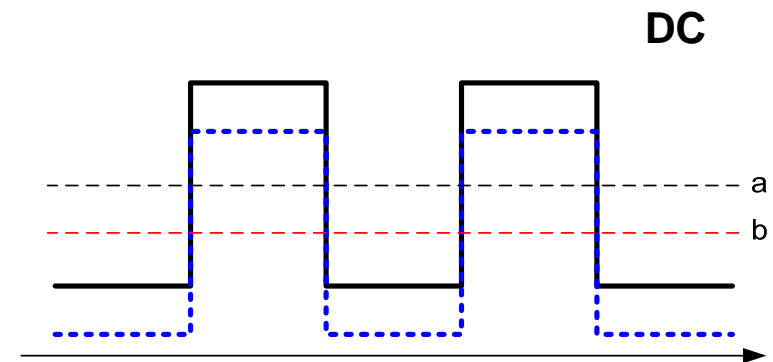
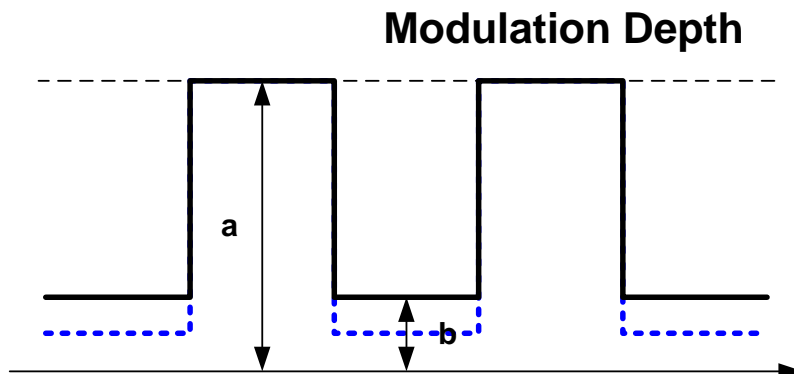
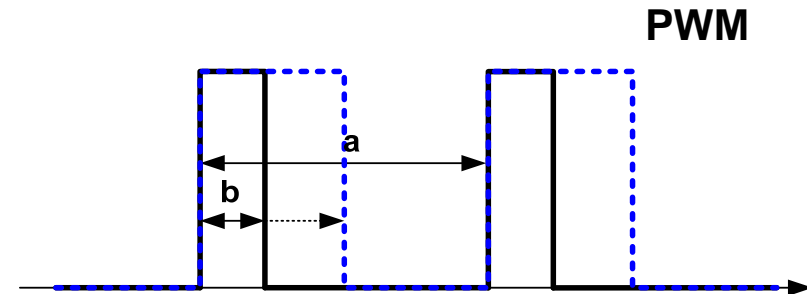
- Current vs. Operating voltage -



- Optical output for PWM duty cycle -

# Illumination + Communication (1/3)

- LED Brightness Control with communication
  - PWM Control (Duty cycle control)
  - DC level control
  - Modulation Depth control





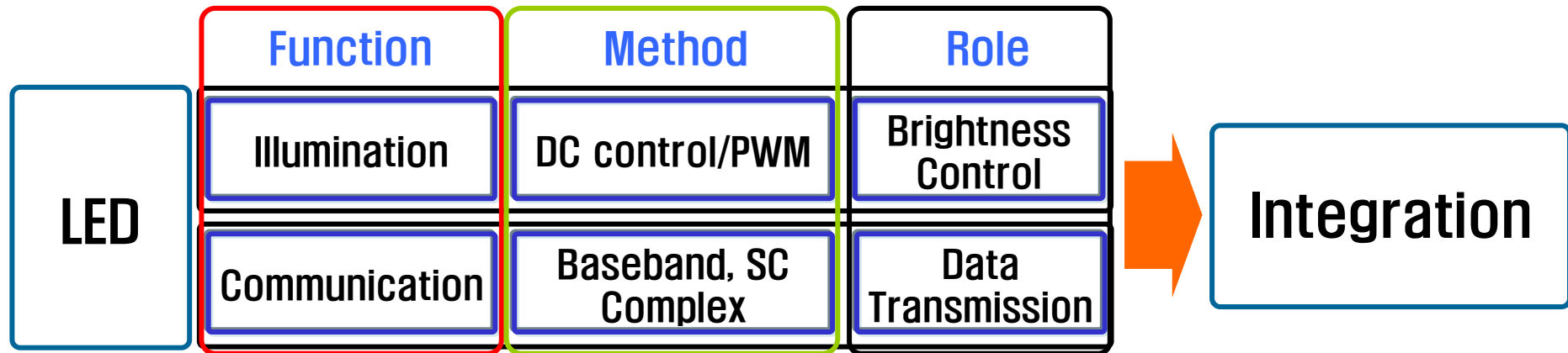
# Illumination + Communication (2/3)

- LED Brightness Control with communication (Current Solution)
  - Use of up to 1kHz PWM signal for brightness control
    - Brightness Control : Adjustment through Pulse Duty Cycle
      - PWM can be realized in digital processor easily without complicated analog circuit.
    - In case of high speed data transmission, it is not to be suitable.
      - Since several times frequency of PWM signal than data rate for communication are actually required.
    - PWM + SC-PPM
      - SC-PPM for communication and PWM for dimmer can be controlled independently.
      - Brightness : high speed PWM for dimmer (by multiplying SC-4PPM)
      - Communication function : SC-4PPM

# Illumination + Communication (3/3)

- LED Brightness Control (Another solution)
  - **Brightness Control : Modulation Depth Control or DC control**
    - High speed data transmission possible
      - Additional PWM signal may not be required.
    - Amplitude Modulation
      - Modulation Depth control
      - Average CW (Manchester Coding)
    - Phase Modulation
      - Constant Intensity (DC)
      - Subcarrier method
      - Brightness: Subcarrier Modulation Depth adjustment
      - Communication: Phase methods (PSK, FSK)

# Characteristics of VLC



Integration Method	Analysis
<b>DC/Modulation depth control based Modulation</b>	<ul style="list-style-type: none"> <li>• Efficient Control of Data Transmission</li> <li>• Brightness : Complex circuit design, nonlinear output</li> </ul>
<b>PWM based Modulation</b>	<ul style="list-style-type: none"> <li>• Brightness : Simple circuit design, linear output control</li> <li>• Independence between comm. and illumination</li> <li>• additional PWM signal generator required</li> <li>• Difficult high speed data transmission because of high speed PWM signal required</li> </ul>

# Summary

## ● VLC modulation issues

- Different approach is required because of illumination function.
  - Mobile-to-Mobile/Mobile-to-Fixed (Between Devices)
    - Communication-centric : various RF/Optics modulation methods may be possible.
  - Infra-to-Mobile
    - Illuminations + Communications
    - Especially, downlink of communications
    - Illumination-compatible modulation method need to be considered.
- Therefore, PHY standard may be reflected the above.