

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

Submission Title: [ETRI PHY proposal on VLC band plan and modulation schemes for illumination]

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Re: [Response to call for proposals]

Abstract: [This document describes a proposal of VLC band plan and modulation schemes for illumination.]

Purpose: [Proposal to IEEE 802.15.7 VLC TG]

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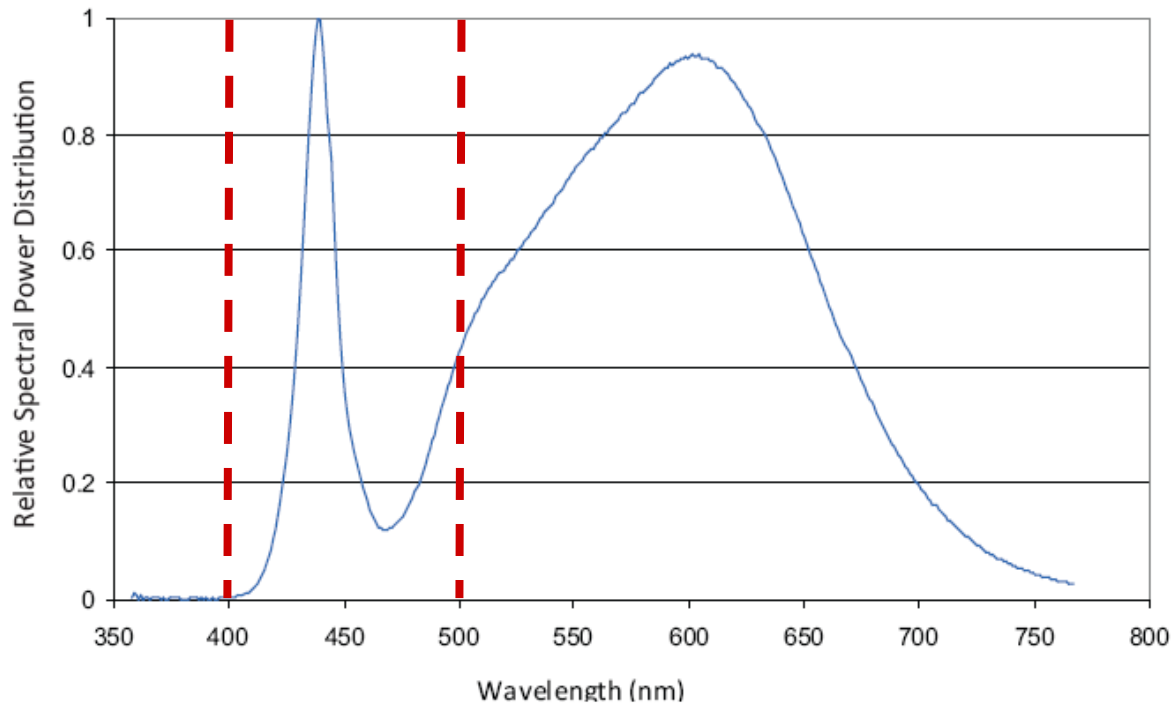
ETRI PHY Proposal on VLC Band Plan and Modulation Schemes for Illumination

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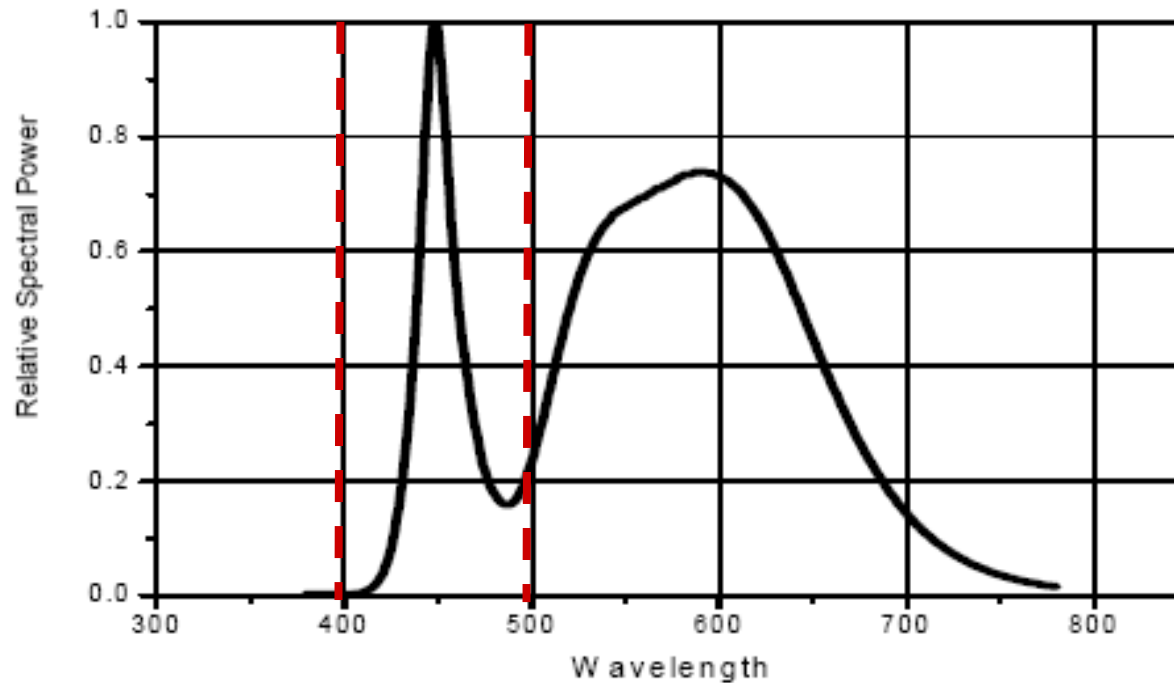
Basis of VLC Band Plan

- **Spectrum Characteristics of LED Light Sources**
- **Optical Filter Characteristics at Receiver**

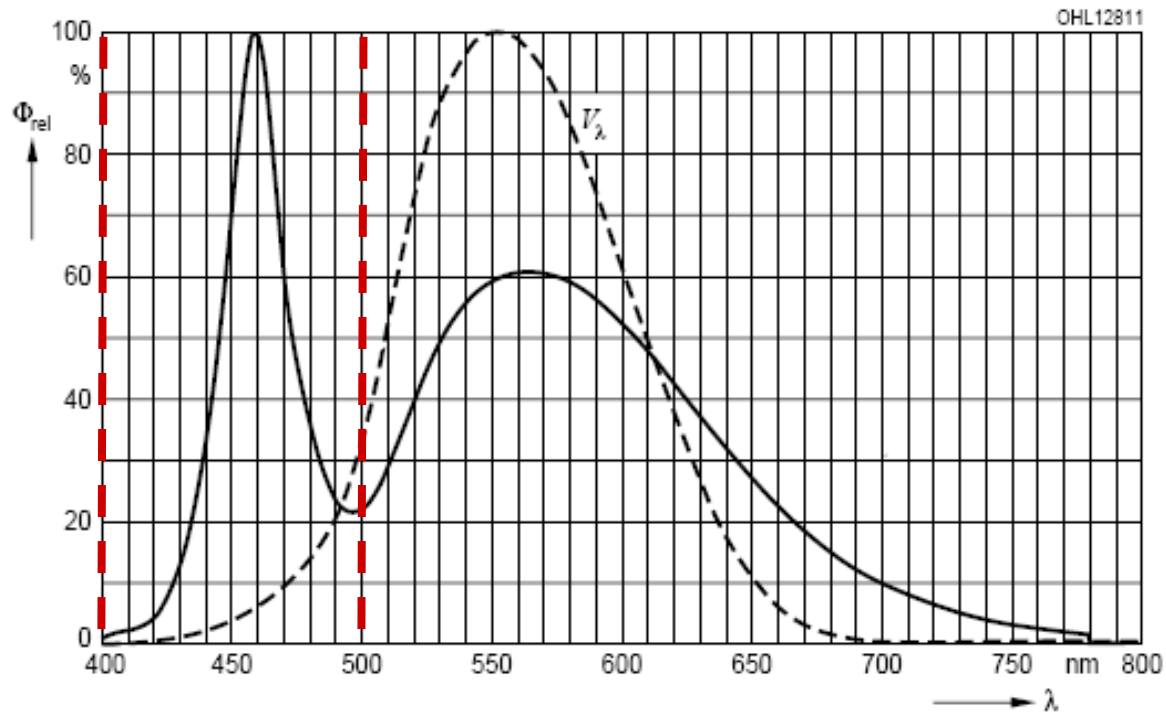
Spectrum Characteristics of Commercial White LED for Illumination (1)



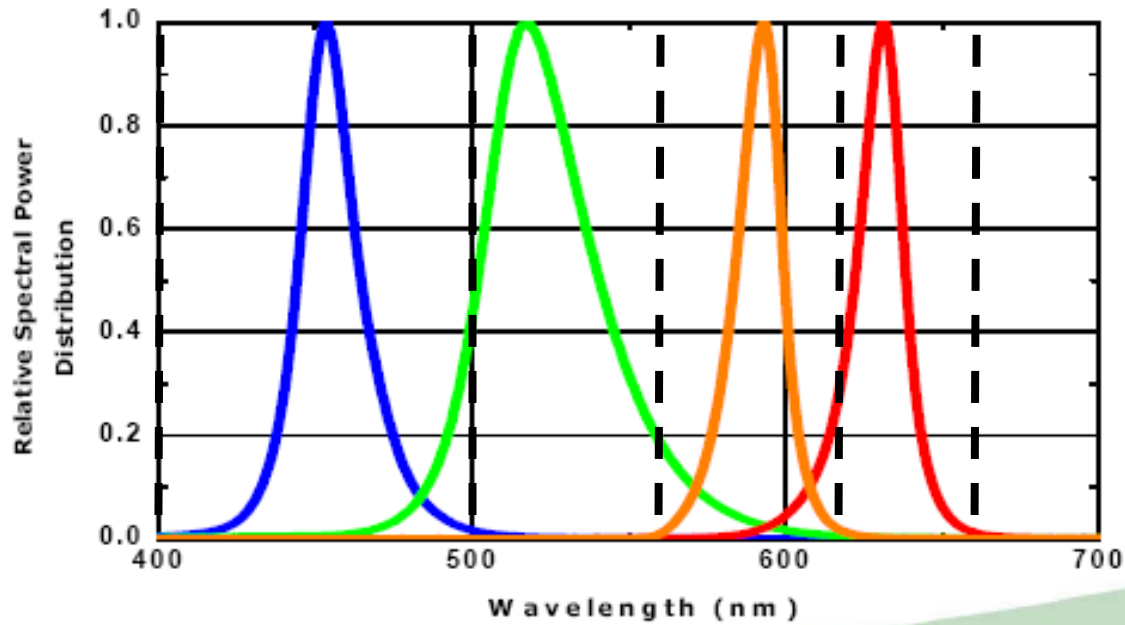
Spectrum Characteristics of Commercial White LED for Illumination (2)



Spectrum Characteristics of Commercial White LED for Illumination (3)



Spectrum Characteristics of Commercial Colorful LED



Proposed Band Plan

Wavelength Band (nm)		Spectral Width (nm)
380	400	20
400	500	100
500	560	60
560	620	60
620	660	40
660	720	60
720	780	60

Main Factors in VLC Modulation Scheme for Illumination

❑ Flicker Removal for Eye Safety

- We must remove the flicker for eye safety.
- If we cannot remove the flicker in VLC for illumination, VLC for illumination disappear.

❑ Dimming Control

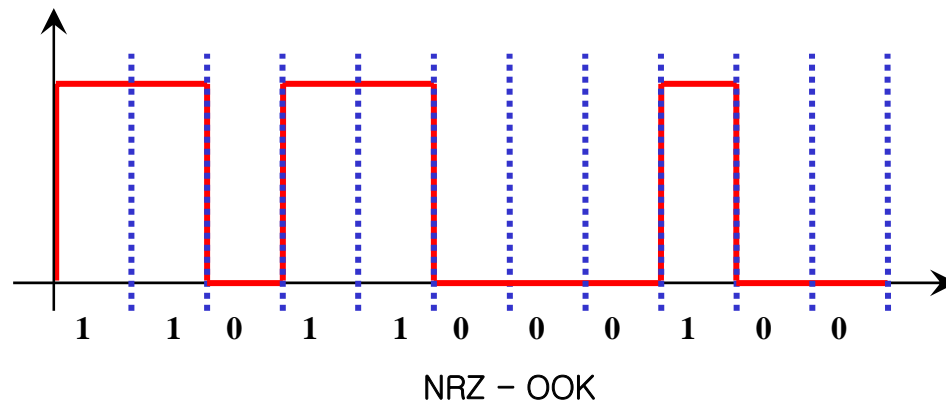
- It will be better that the dimming control function of LED light for VLC and illumination is also alive because even LED light only for illumination provides it.

❑ Full Brightness

- It is desirable that VLC for illumination achieve the full brightness as much as LED light only for illumination do.

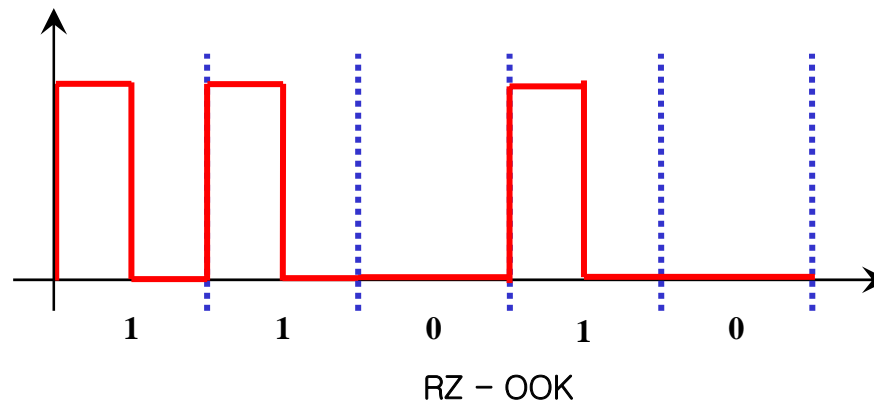
NRZ - OOK

- ❑ NRZ-OOK is one of the simple modulation scheme and a kind of amplitude-shift keying (ASK) modulation that represents digital data of “1” or “0” as the “on” or “off” states
- ❑ Without line code, the flicker may be.
- ❑ It is difficult to achieve the dimming control and full brightness.



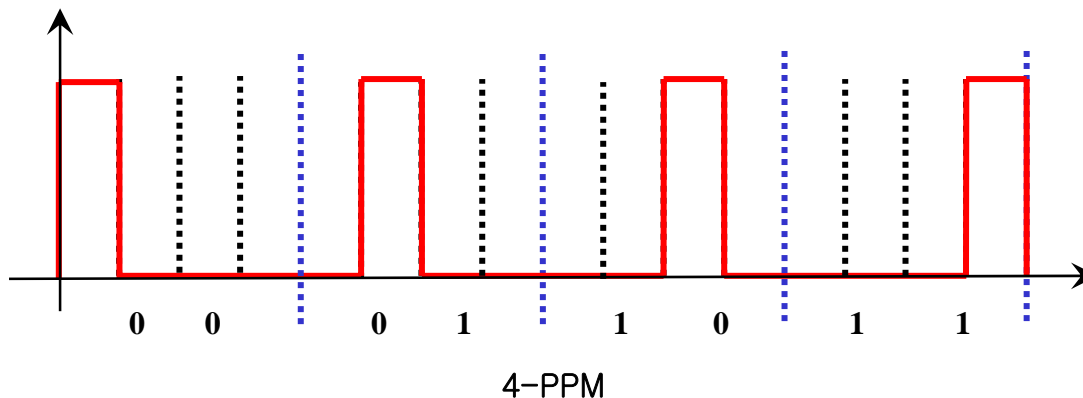
RZ - OOK

- ❑ RZ-OOK is one of the simple modulation scheme and a kind of amplitude-shift keying (ASK) modulation that represents digital data of “1” or “0” as the “on” or “off” states
- ❑ Without line code, the flicker may be.
- ❑ It is difficult to achieve the dimming control and full brightness.



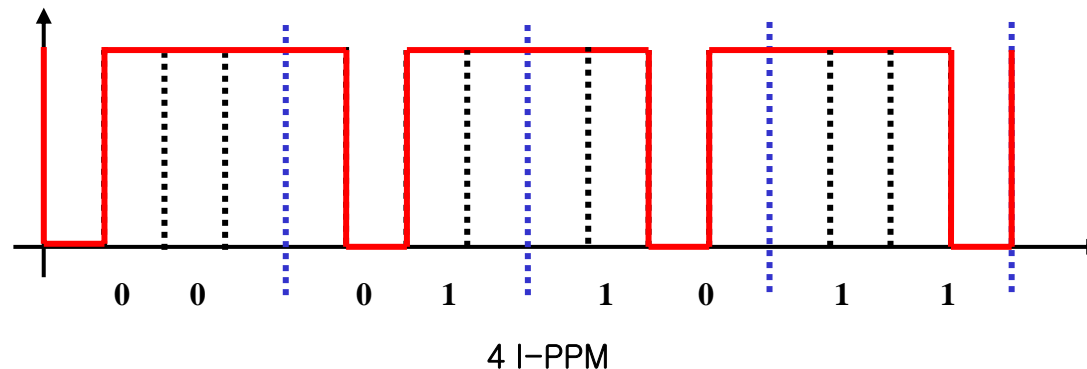
PPM (Pulse Position Modulation)

- ❑ M message bits are encoded by transmitting a single pulse in one of 2^M possible time-shifts.
- ❑ The flicker is free.
- ❑ It is difficult to achieve the dimming control and full brightness.



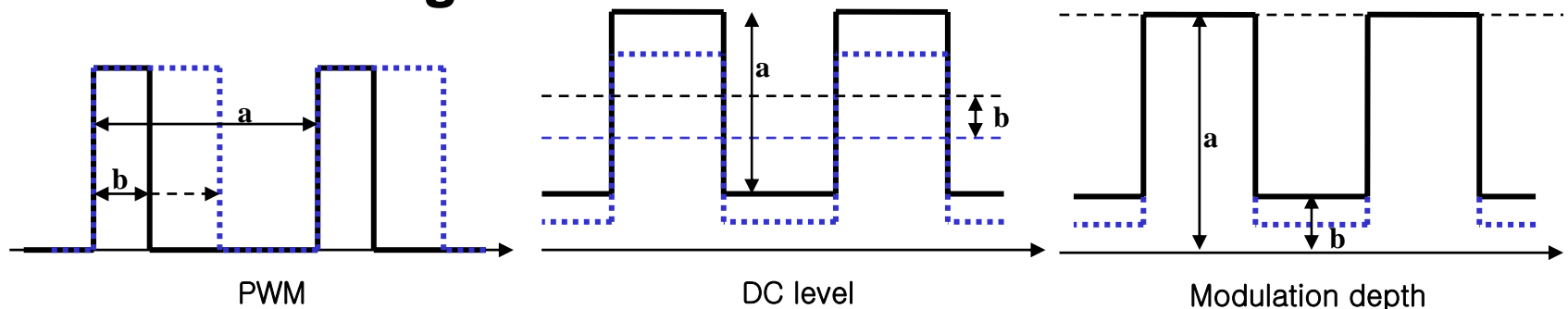
I - PPM (Inverse - PPM)

- ❑ M message bits are encoded by transmitting a single pulse in one of 2^M possible time-shifts.
- ❑ Flicker is free.
- ❑ We can obtain the full brightness, but it is difficult to achieve the dimming control.



PWM (Pulse Width Modulation)

- ❑ PWM is the modulation scheme widely used in LED illumination for itself.
- ❑ So, we can basically achieves the flicker-free, the dimming control, and the full brightness by using PWM.
- ❑ If we use PWM only itself for VLC, we cannot obtain the flickering-free, the dimming control, or the full brightness.

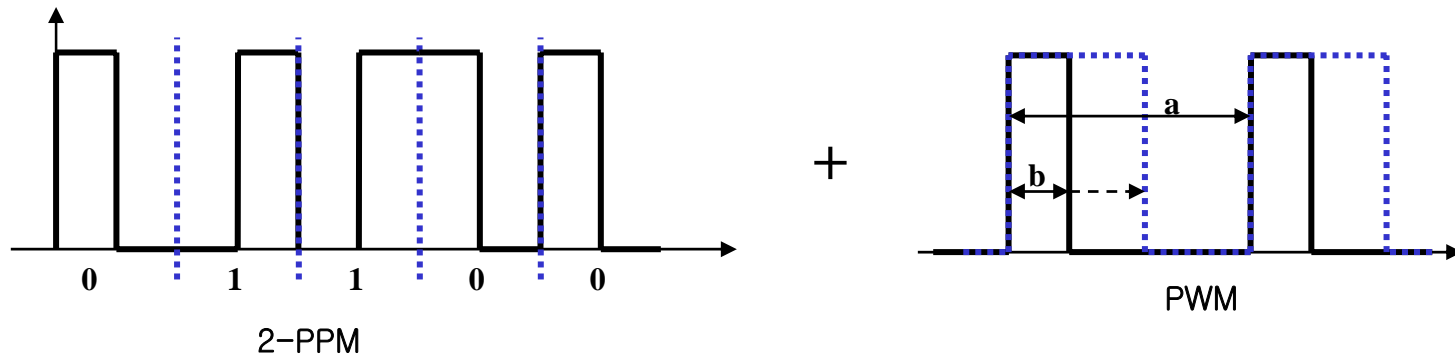


*15-08-0430-00-0vlc-modulation-categorization-of-vlc.pdf, Huck-Choon Kwon, Samsung

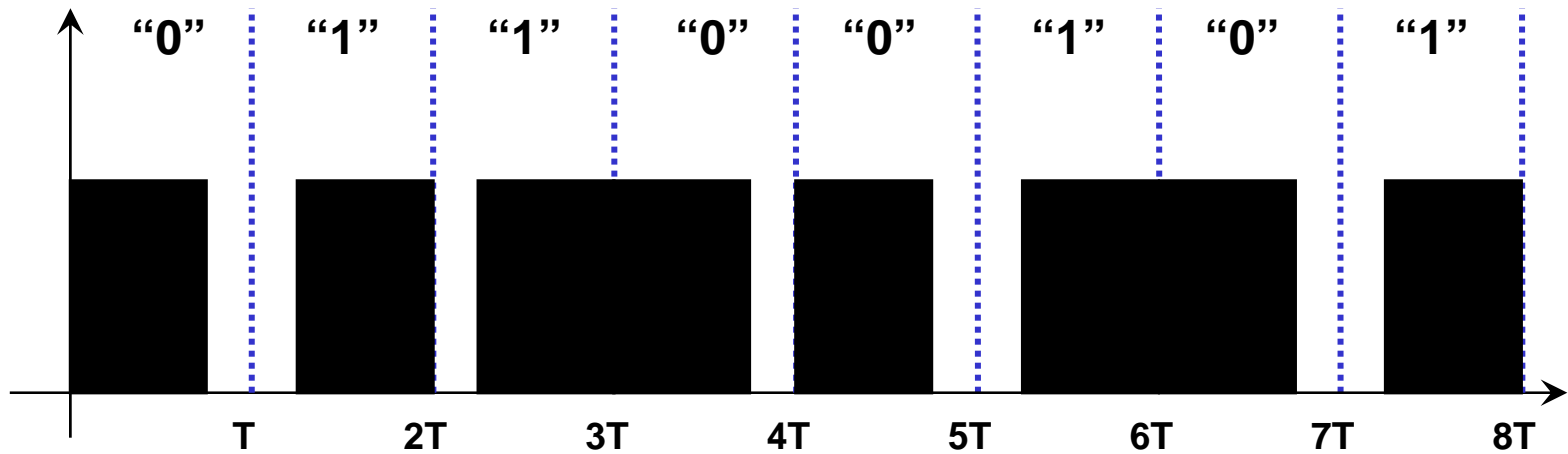
Features of VPM (Variable PPM) Proposed by ETRI

□ Variable-PPM = PWM + 2-PPM

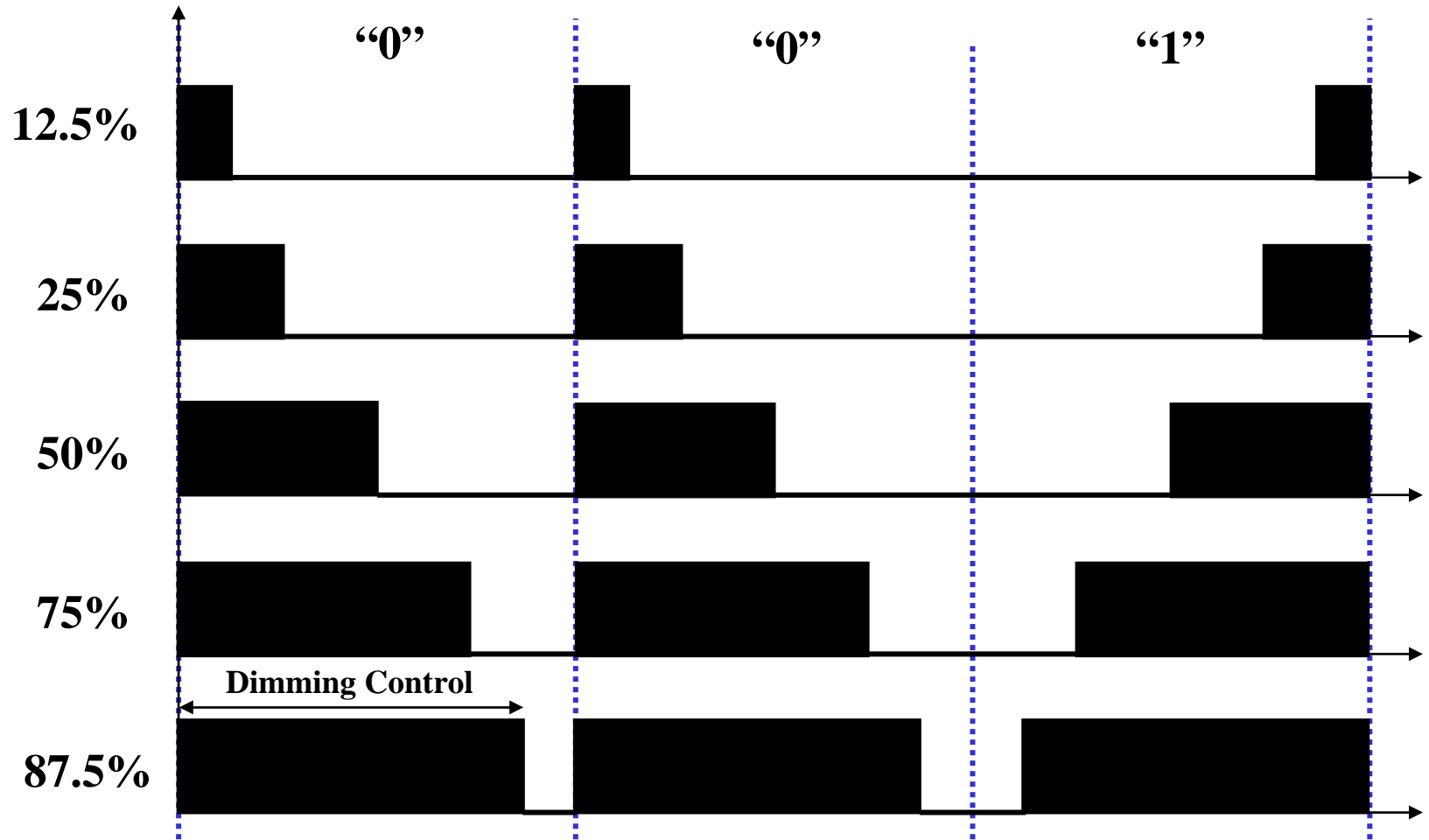
- For communication, use 2-PPM
- For brightness control, use PWM (duty cycle control)
- VPM equals to 2-PPM when the duty of VPM is 50 %.



Example Waveform of Proposed VPM with 75% duty



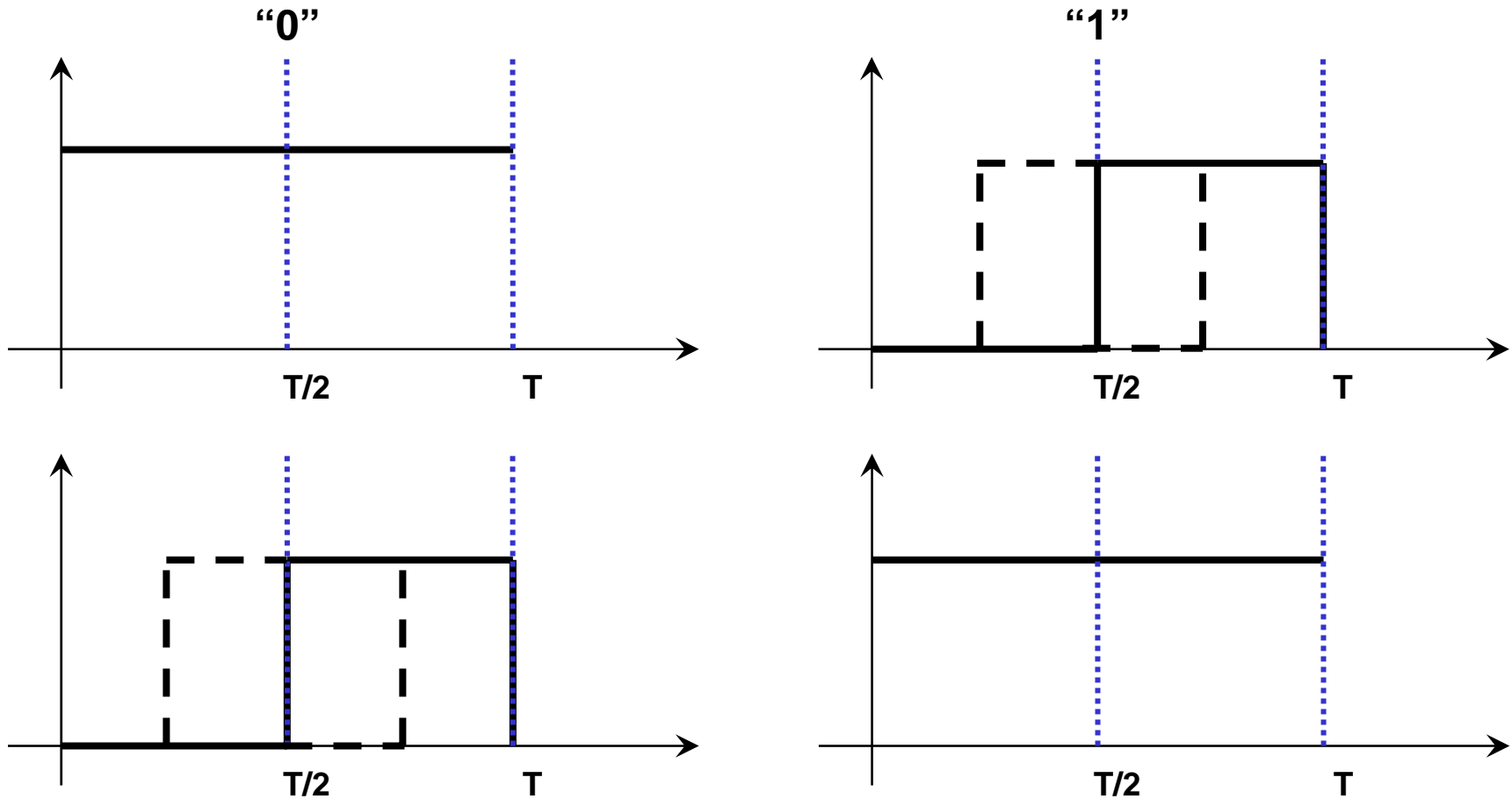
Dimming Control by Proposed VPM Signal



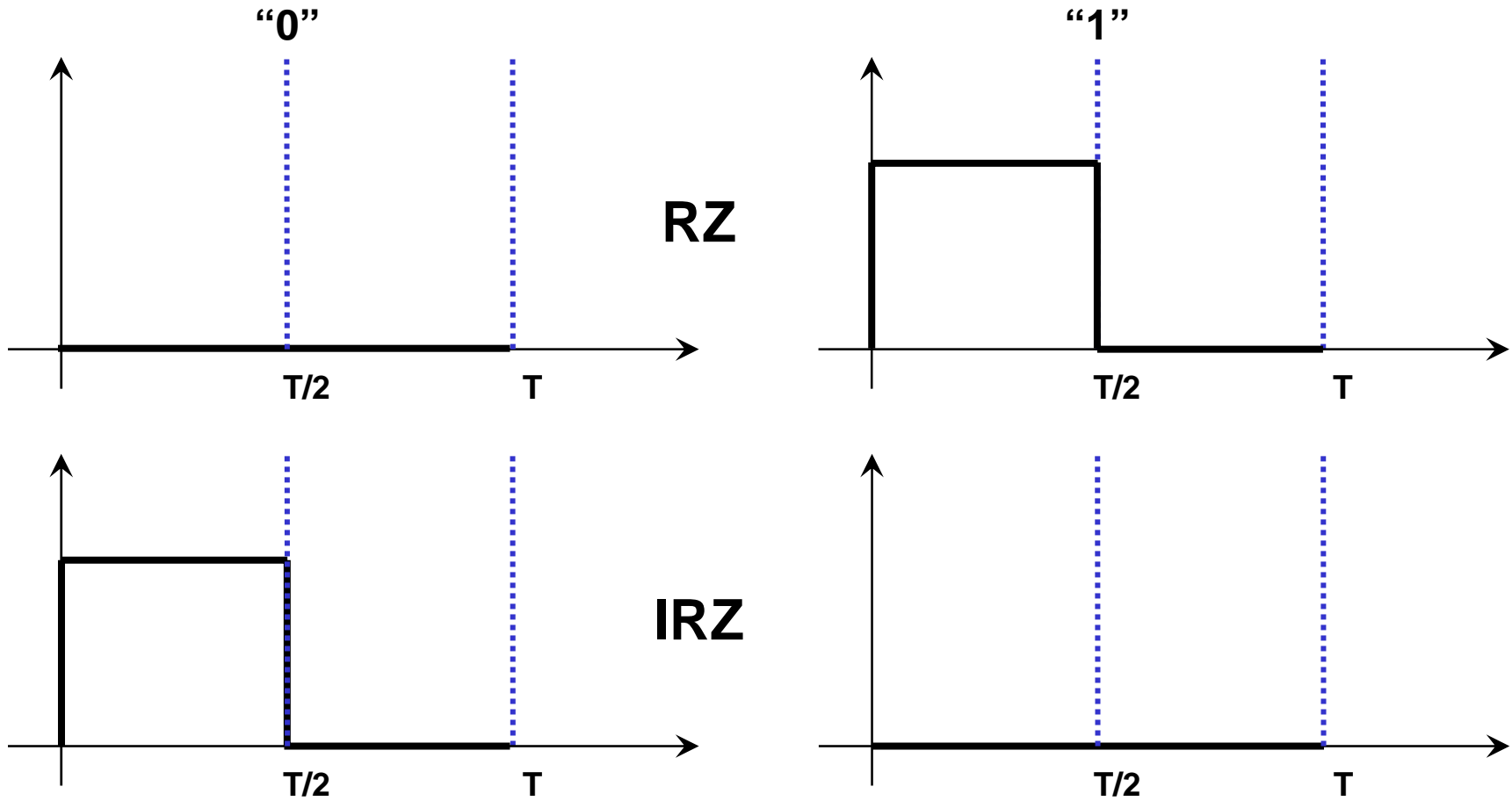
Advantages of VPM

- ❑ Flicker-free signal only by using VPM without line code because the “on” state area of LED light is always constant under the given duty cycle.**
- ❑ Dimming control by the duty cycle adjustment.**
- ❑ Full brightness by the increase of the duty cycle resolution.**

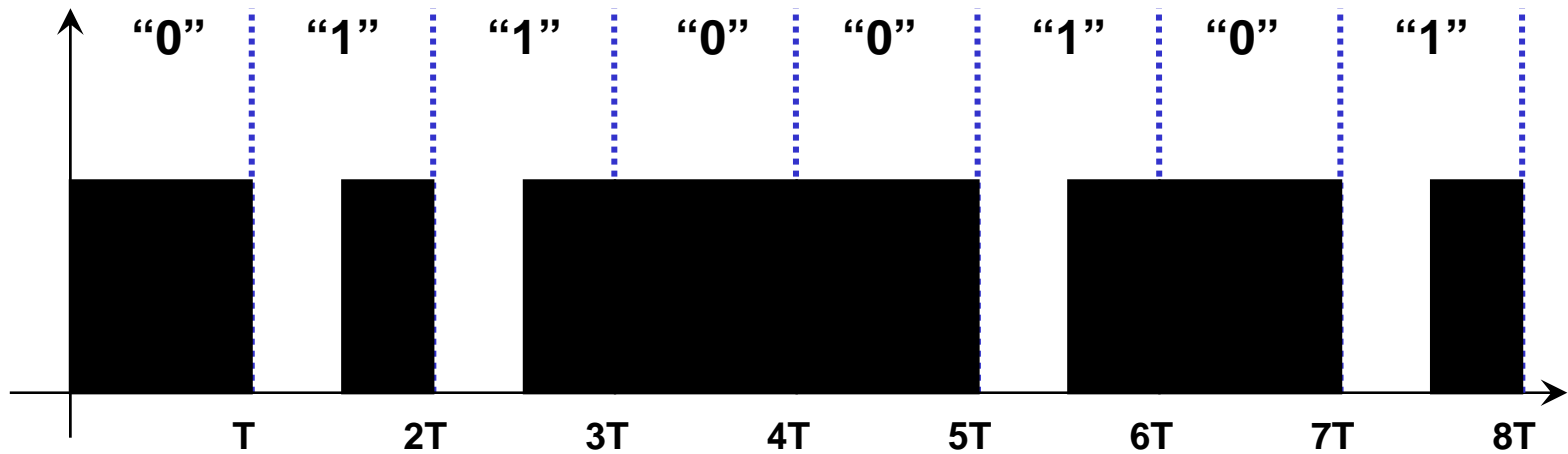
Features of Reverse-RZ with Variable Duty proposed by ETRI



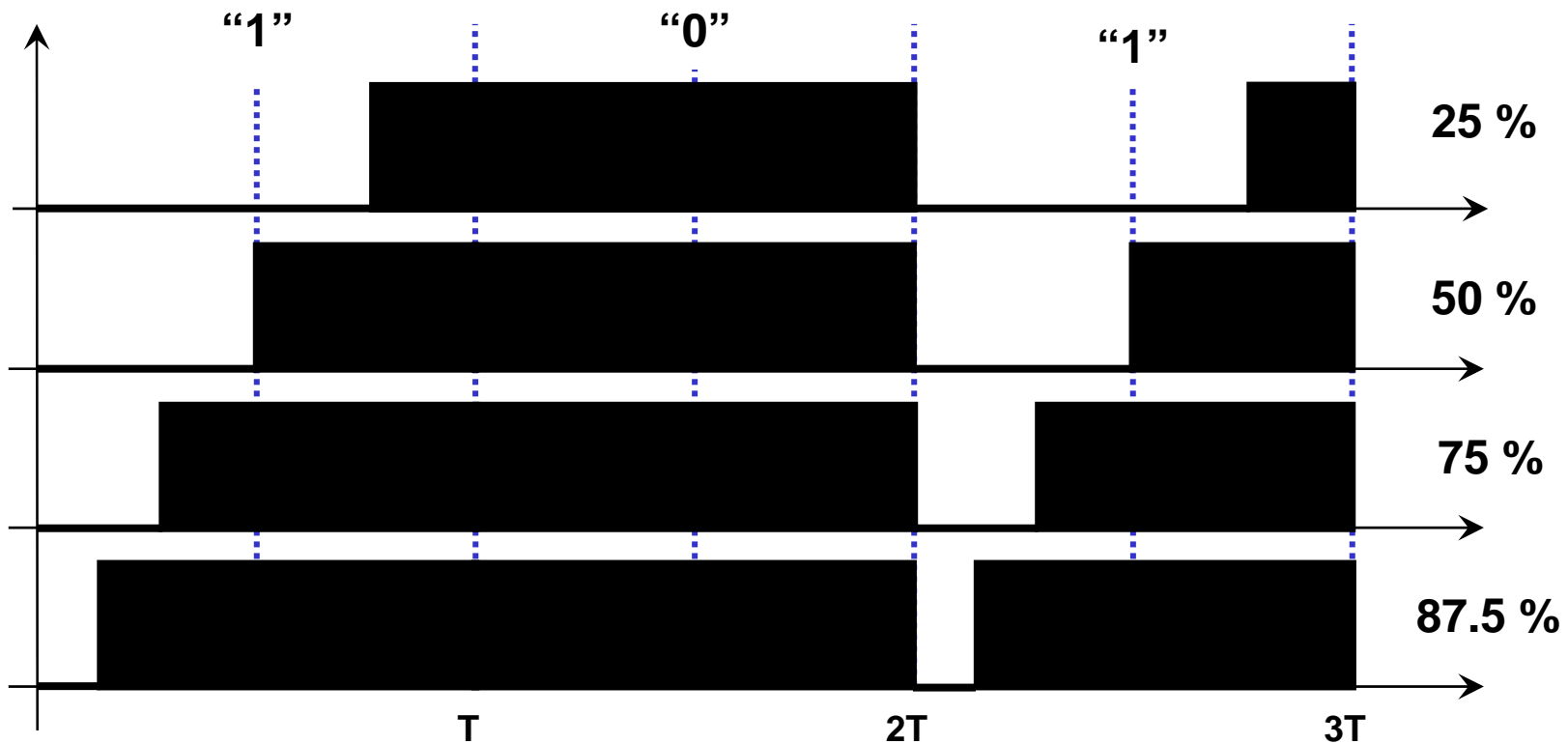
Features of Typical RZ and IRZ Signal



Example Waveform of Proposed Reverse-RZ Signal with 50% duty



Dimming Control by Proposed Reverse-RZ Signal with Variable Duty



Advantages of Reverse-RZ with Variable Duty

- ❑ **Flicker-free signal by using R-RZ with 4B6B or advanced 4B-5B line codes because 4B6B or advanced 4B-5B line codes makes the “on” state area of LED light be always constant under the given duty cycle.**
- ❑ **Dimming control by the duty cycle adjustment.**
- ❑ **Full brightness by the increase of the duty cycle resolution.**

Comparison and Our Proposal of VLC Modulation Scheme for Illumination

	Flickering-free	Dimming Control	Full Brightness
NRZ-OOK	O / w LC	X	X
RZ-OOK	O / w LC	X	X
PPM	O	X	X
I-PPM	O	X	O
PWM (not for VLC)	O	O	O
VPM	O	O	O
R-RZ	O / w LC	O	O

(w LC : with Line Code)