

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

Submission Title: [ETRI PHY Proposal on VLC Line Code for Illumination]

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Re: [Response to call for proposals]

Abstract: [This document describes a proposal of PHY line code for LED illumination]

Purpose: [Proposal to IEEE 802.15.7 VLC TG]

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ETRI PHY Proposal on VLC Line code for Illumination

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ETRI

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ETRI PHY Considerations based on TCD

- Target Application
 - VLC using the Illumination at office/home environment
 - White LED & RGB LED
- Considered data rate and range: A1*
 - Infrastructure to mobile
 - High data rate: 1Mbps~
 - Short range: $\leq 3\text{m}$
- Divergence angle of illumination
 - Very various
 - LED fluorescent: $110^\circ \sim 310^\circ$
 - PAR type: $60^\circ \sim 140^\circ$ ($30^\circ \sim 40^\circ$ is possible)

*15-09-0564-01-007 TCD Table 5

ETRI PHY Scope

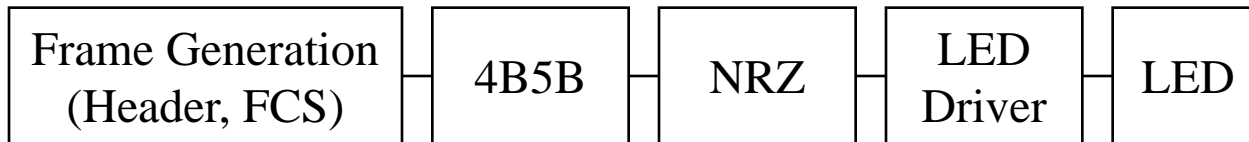
- Office/Home illumination
 - Infrastructure to mobile
- Transmission device
 - white LED (yellow phosphor)
 - R, G, B LED
- Data rate and range
 - 1Mbps(DL/UL) @2.5m
- Directivity
 - Bi-directional (Full or Half), Uni-directional

ETRI PHY Proposal

- Line code
 - 4B6B
 - Modified-4B5B: M-4B5B
- Modulation
 - Variable Pulse Position Modulation: VPM
 - Reverse-Return to Zero: R-RZ
- Multiplexing
 - Time Division Multiplexing(TDM) for LED signboard

PHY Model using typical technique

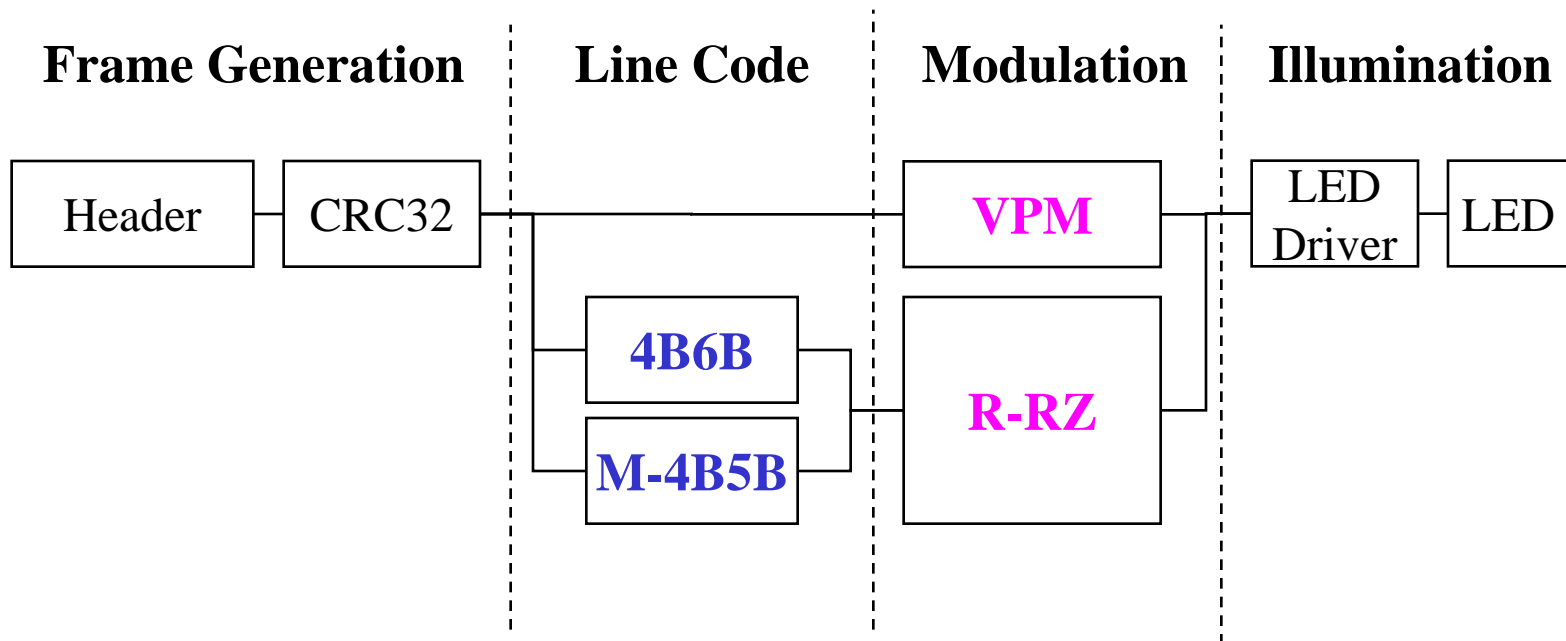
- A model for VLC PHY



- Defect of 4B5B and NRZ for illumination
 - Flickering
 - According to data pattern
 - Existence of data frame
 - Dimming
 - Very difficult control

ETRI PHY Model

- ETRI PHY models for dimmable and non-flickering illumination



Flickering definition and source

- Unexpected and unpredictable light intensity change recognized by human eyes
 - Repetition of On and Off
 - Slow change of brightness
- Flickering in VLC
 - Low Data rate
 - Recognizable 'on' and 'off' of light source
 - Data pattern
 - When VLC use NRZ OOK, data pattern is 'on' and 'off' pattern of light source
 - Long sequence of 1 or 0
 - 0000 0001 0101 0111 1111 1110 1010 1000 0000

Flickering decision condition

- Need to define flickering at VLC
- Maximum Flickering Time Period (MFTP)
 - Period that light intensity can be changed, but that can not be recognized the change of brightness by human eyes
 - $1/\text{minimum flickering free frequency}(200\text{Hz}) = 5\text{ms}$
 - Brightness of each MFTP must be all equal
- Regulation issues
 - Flickering definition
 - Max Flickering Time Period

Solutions for Flickering removal

- Constant ratio of positive (on) and negative (off) level per MFTP
 - Constant-weight code
 - Manchester code (50% duty cycle)
 - 2PPM (50% duty cycle), 4PPM (25% duty cycle)
- Constant ratio of '1' and '0' at data stream per MFTP
 - Scrambler
 - New line code scheme

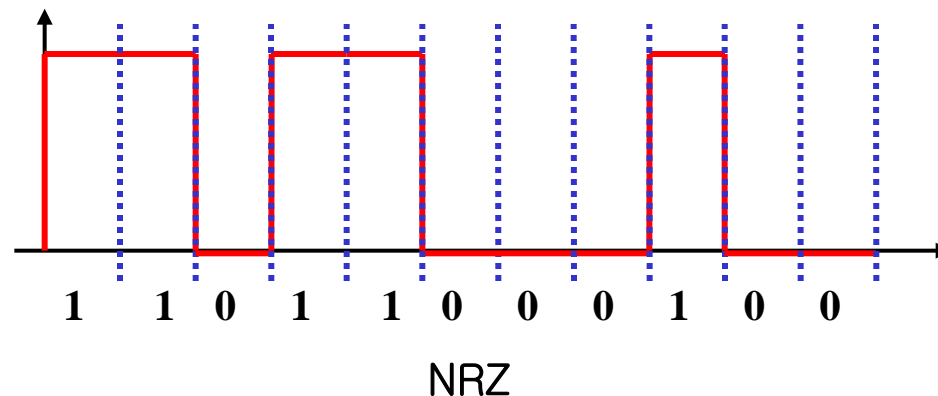
Line code

- The waveform pattern of voltage or current used to represent the 1s and 0s of a digital signal on a transmission link is called **line encoding**.^{*}
 - For reliable clock recovery at the receiver
 - For eliminating DC component
 - eliminate long sequences consisting of '0' or '1' only
- NRZ, 4B5B, Manchester code, ...
- If we use NRZ OOK for VLC modulation, we need to consider line code, such as 4B5B, 8B10B, and so on.

^{*}wikipedia (www.wikipedia.org)

Characteristics of NRZ

- Very simple and general technology at fiber optical communication
- NRZ Can make Flickering by
 - Data pattern
 - Existence of data frame



Characteristics of 4B5B

- a line code that maps 4-bit symbols to 5-bit symbols
- to achieve DC-balance and bounded disparity, and yet provide enough state changes to allow reasonable clock recovery
- Used at
 - PCI Express, Gigabit Ethernet, USB 3.0

Modified-4B5B (M-4B5B)

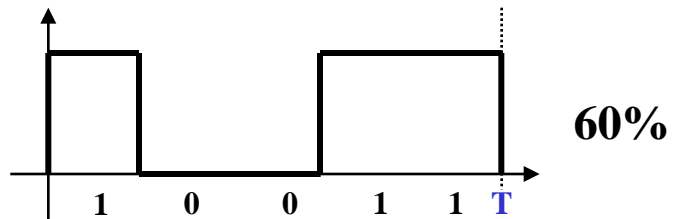
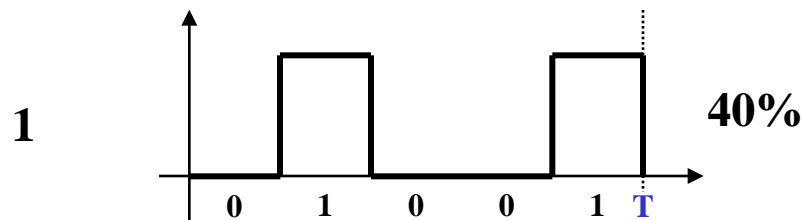
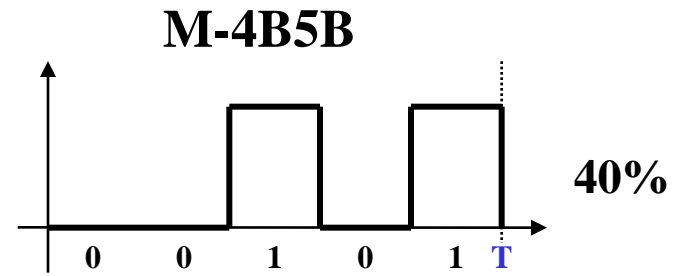
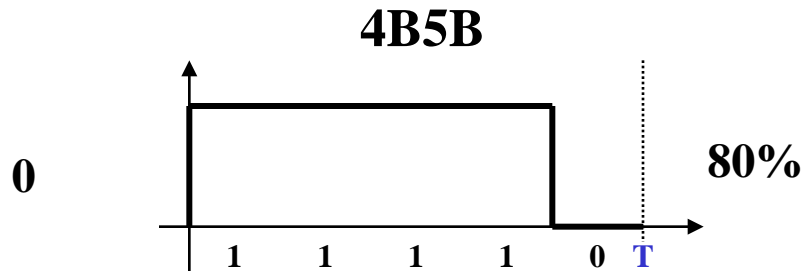
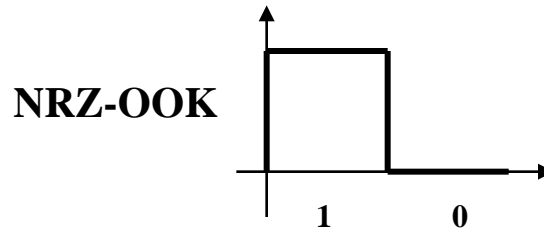
- Minimize the variation of ratio of '1' and '0'
 - At 4B5B
 - 4:1(80%,5), 3:2(60%,7) and 2:3(40%,4)
 - At M-4B5B
 - 3:2(8), 2:3(8)
- Idle time pattern
 - 00011 00111
- Preamble pattern
 - 11000 11100

	4B	5B	M-4B5B
0	0000	11110	00101
1	0001	01001	10011
2	0010	10100	00110
3	0011	10101	10101
4	0100	01010	01001
5	0101	01011	10110
6	0110	01110	01010
7	0111	01111	11001
8	1000	10010	01100
9	1001	10011	11010
A	1010	10110	10001
B	1011	10111	01011
C	1100	11010	10010
D	1101	11011	01101
E	1110	11100	10100
F	1111	11101	01110

Features of M-4B5B

- Almost 50% duty cycle more than 4B5B
- Reduced run length 8 to 4
- Maintains a coding rate 4/5
- Poor error detection
 - Can not detect $1 \rightarrow 0$ at 3:2, $0 \rightarrow 1$ at 2:3
 - 0:0**0**101 \leftrightarrow 0**1**101:D
 - Can not detect the position change of 1 and 0
 - 0:0**0**101 \leftrightarrow 0**1**001:1
- General line code features
 - Clock recovery, DC-balanced waveform

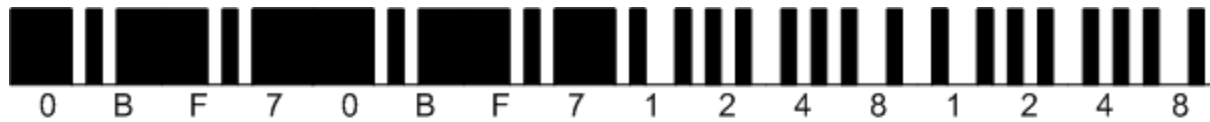
4B5B and M-4B5B at NRZ OOK



Flickering at NRZ OOK using 4B5B and M-4B5B

80%

40%



4B5B

60%

MFTP

40%



M-4B5B

Proposed Line Code - 4B6B

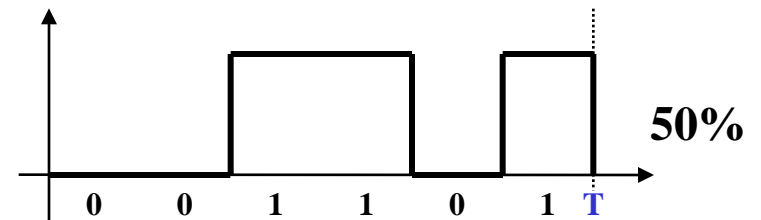
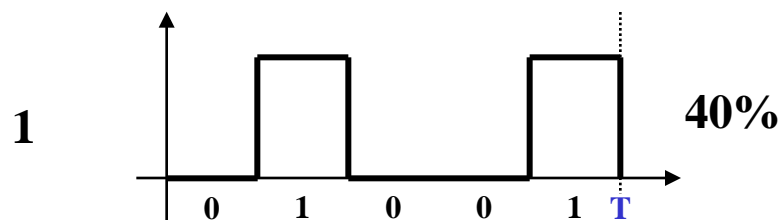
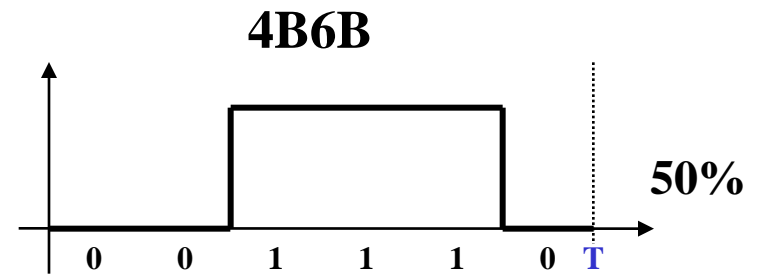
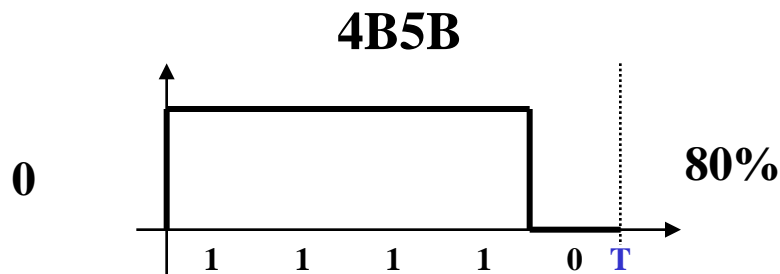
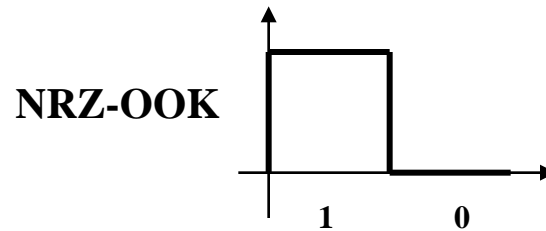
- Expands 4-bit codes to 6-bit symbols
- Same ratio of 1 and 0 (3:3)
 - 50% duty cycle
- Idle time pattern
 - 111000 000111
- Preamble pattern
 - Combination of 110100 and 001011

	4B	5B	6B
0	0000	11110	001110
1	0001	01001	001101
2	0010	10100	010011
3	0011	10101	010110
4	0100	01010	010101
5	0101	01011	100011
6	0110	01110	100110
7	0111	01111	100101
8	1000	10010	011001
9	1001	10011	011010
A	1010	10110	011100
B	1011	10111	110001
C	1100	11010	110010
D	1101	11011	101001
E	1110	11100	101010
F	1111	11101	101100

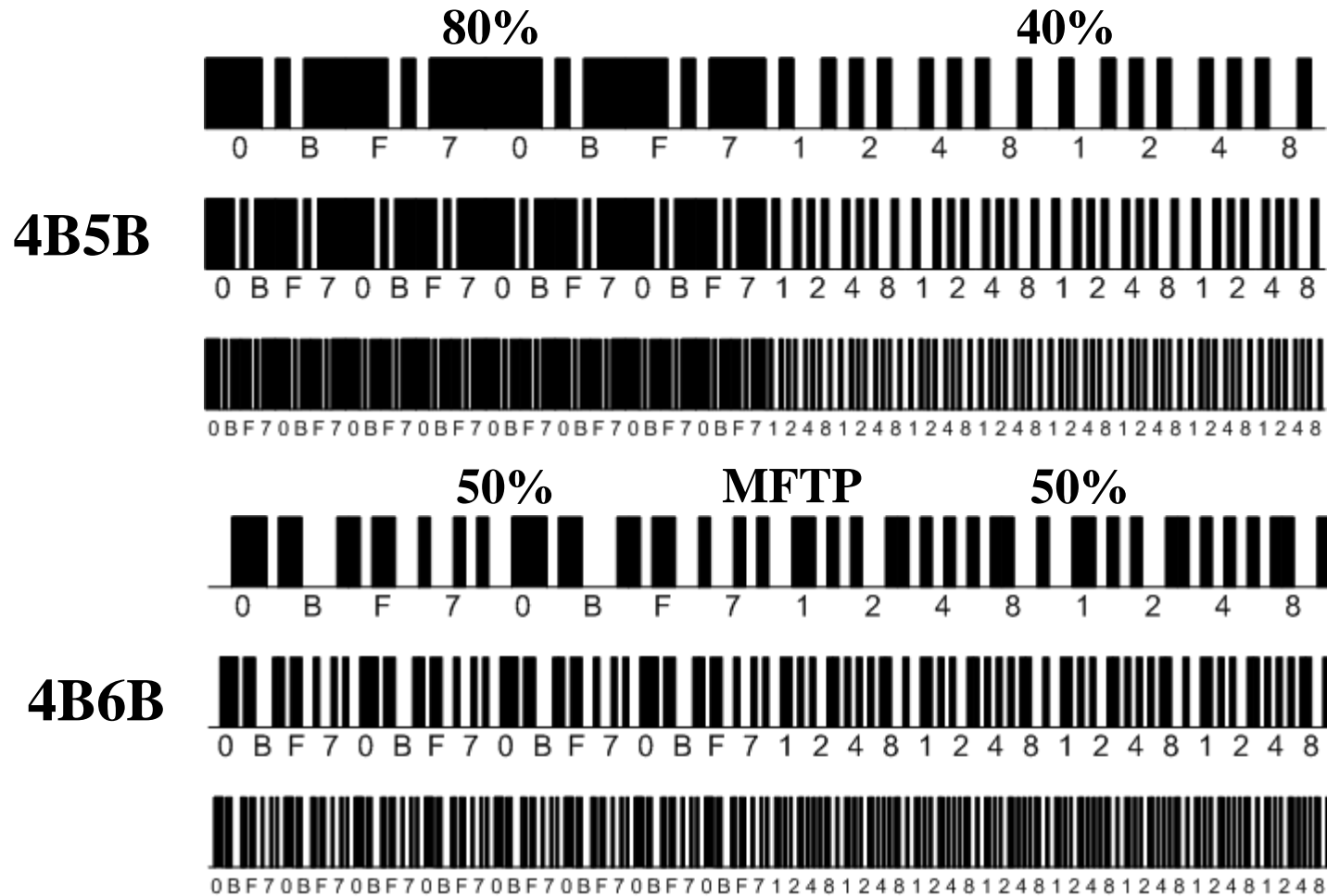
Features of 4B6B

- Always 50% duty cycle
- Reduced run length 8 to 4
- Error detection
 - Can detect error by number of 1 and 0
 - Can not detect the position change of 1 and 0
 - 0: 001110 ↔ 001101 :1
- General line code features
 - Clock recovery, DC-balanced waveform

4B5B and 4B6B at NRZ OOK



Flickering at NRZ OOK using 4B5B and 4B6B



Conclusions and Proposals

- Flickering is a very important factor in terms of illumination
 - Flickering free technology is required
- Propose 4B6B and M-4B5B
 - Flickering free/less line code
 - Reduced run length
 - Support general line code features
 - Propose Idle and preamble pattern