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

**Submission Title:** [Color Multiplex Coding for VLC]
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**Re:** []

**Abstract:** [The introduction of the Color Multiplex Coding (CMC) for VLC and its evaluation results. The BER performances are showed by simulation and experiment.]

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

# Color Multiplex Coding for VLC

2008.11.13

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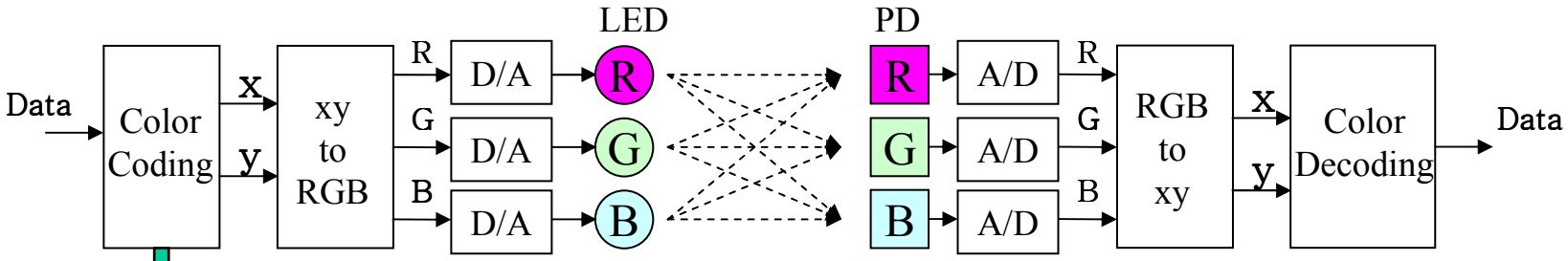
# Introduction

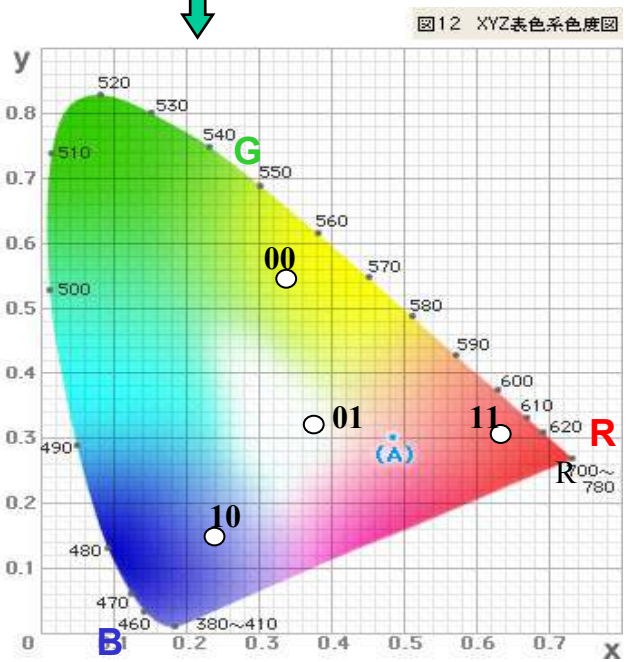
- WDM (Wave Length Multiplex) is good modulation scheme for realizing high speed transmissions.
- The wave length and number have to be selected carefully, and those decide devices(LED,PD) and the performance of VLC systems.

- CMC (Color Multiplex Coding) is a new modulation scheme which we propose.
- It doesn't depend on the wave length and number directly.
- It can be expected better flexibility for VLC system than WDM.

# What is CMC?




CMC system block diagram




CIE1931 xy color coordinate

- Data train is coded in the xy color coordinate.
- xy values are transformed into RGB values.
- The relation between xy and RGB is showed by following equations according to "CIE1931 RGB color space".
  (R:700nm, G:546.1nm, B:435.8nm)

$$X = 2.7689R + 1.7517G + 1.1302B$$

$$Y = R + 4.5907G + 0.0601B$$

$$Z = 0.0565G + 5.5943B$$

$$x = X/(X+Y+Z)$$

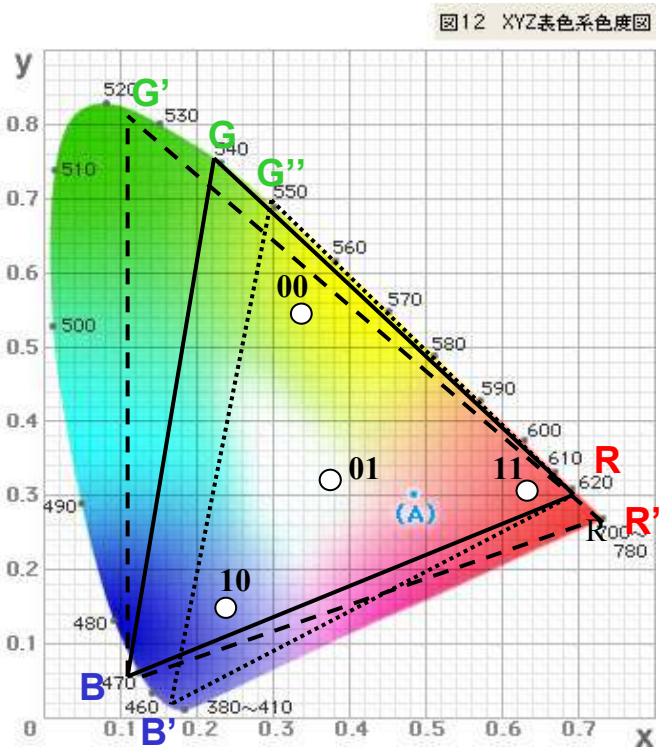
$$y = Y/(X+Y+Z)$$

# Why CMC?

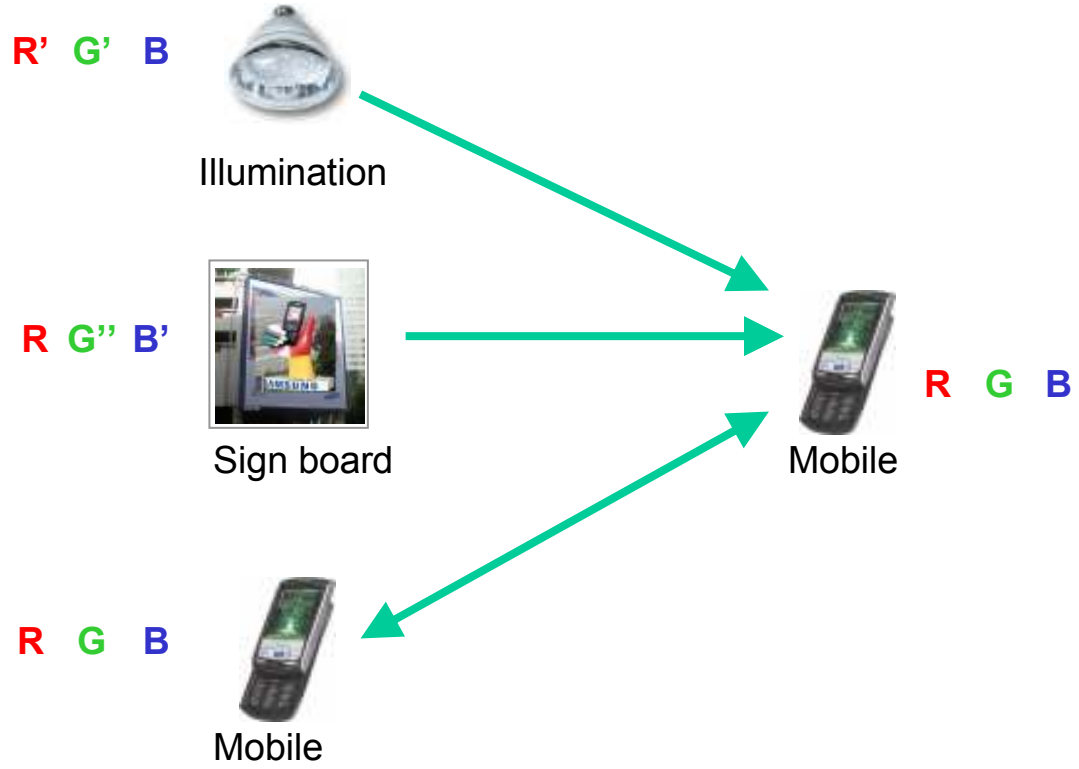
- WDM
  - Transmit data is distributed to RGB channels.
  - The channels are decided by the wave length and number.
  - Same wave length sources and detectors are required.
  - System flexibility is lower.

- CMC
  - Transmit data is allocated in the color coordinate plane.
  - The channels are decided by the color coordinate.
  - It doesn't depend on the wave length and number directly.
  - System flexibility is higher.

# Why CMC?

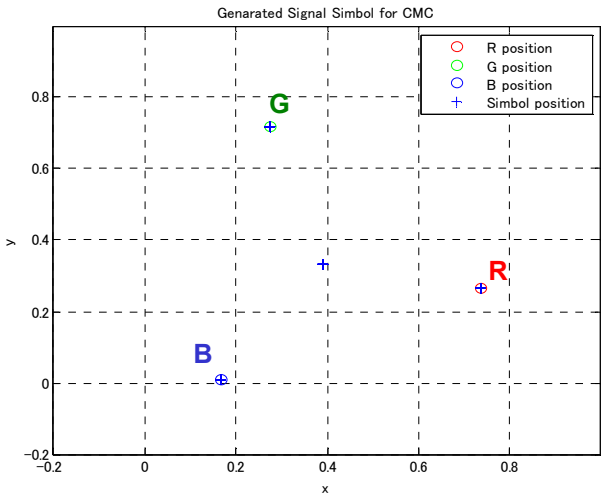



xy color coordinate

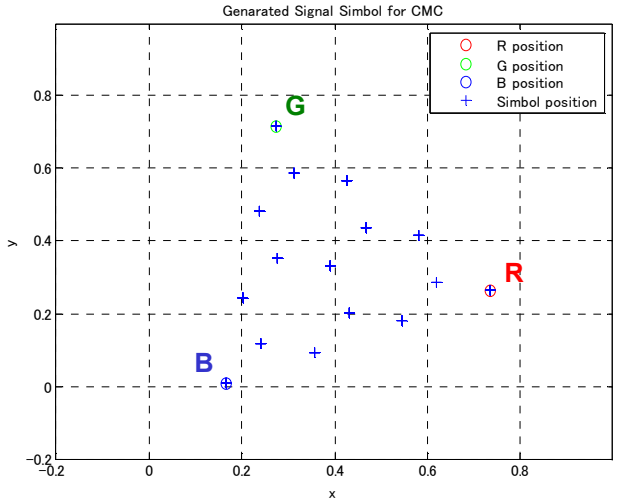



- Light source spectrum are different among the various devices.
- CMC symbols are produced by several light sources according to the color coordinate.
- CMC symbols can be produced and reproduced by different light sources.
- CMC guarantees the connectivity each device with xy color coordinate.

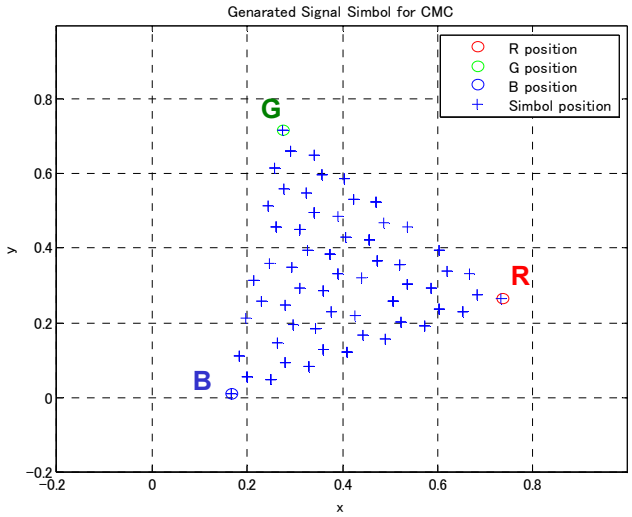
# CMC simulation




4 CMC
(2bits/Symbol)




16 CMC
(4bits/Symbol)



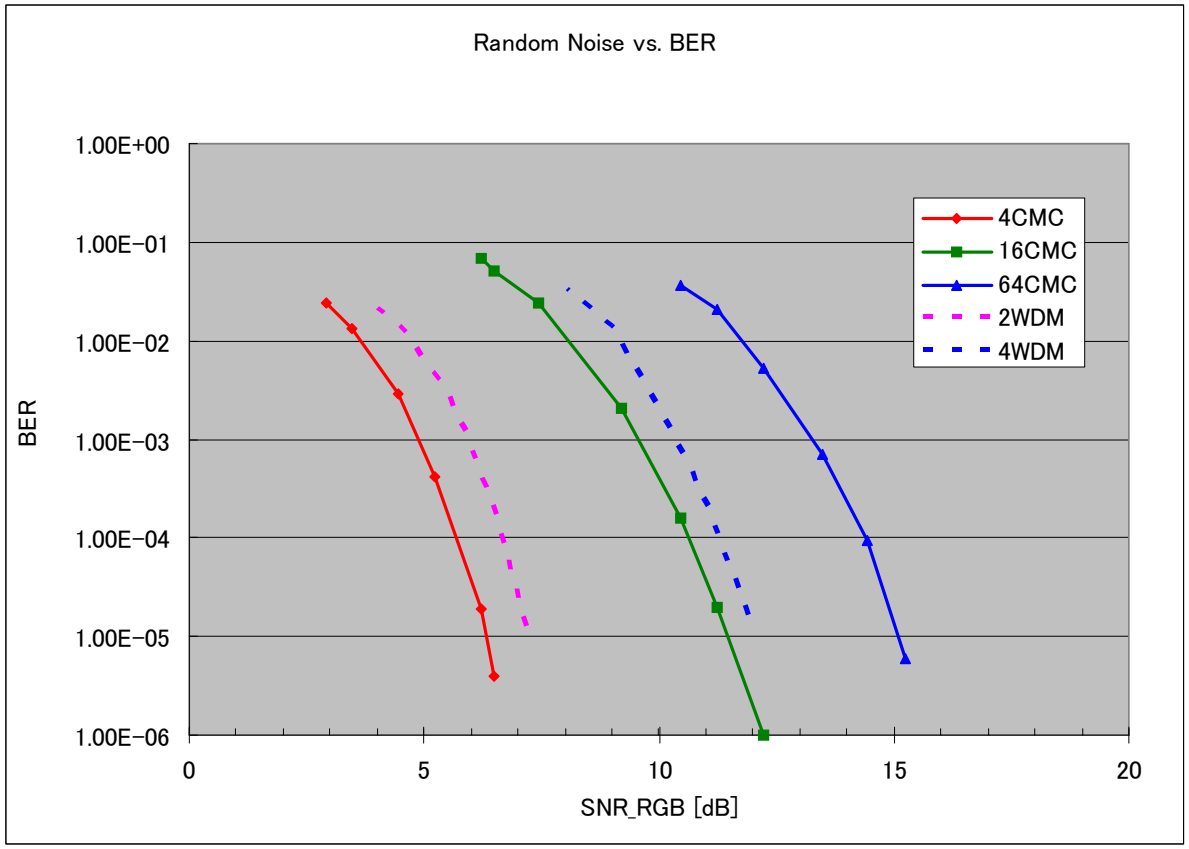

64 CMC
(6bits/Symbol)

Symbol position in xy color coordinate for CMC performance evaluation

- Those symbol positions were decided for having same and max distance from adjacent symbols.

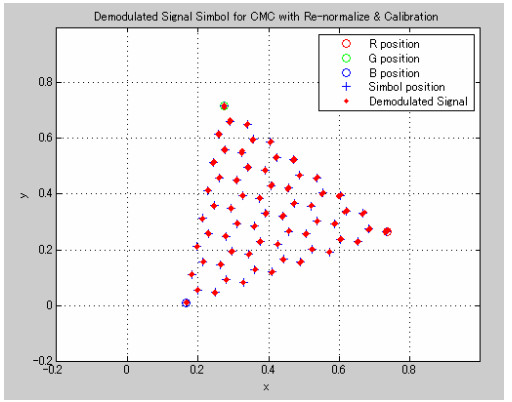
4CMC：4points Color Multiplex Coding（2bits/symbol)
16CMC：16points Color Multiplex Coding（4bits/symbol)
64CMC：64points Color Multiplex Coding（6bits/symbol)

# BER performance with random noise

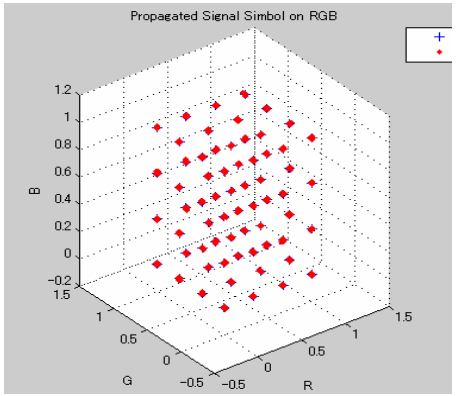



2WDM：2level(On-Off)/color WDM（3bits/symbol） with Random Noise

4WDM：4level/color WDM（6bits/symbol） with Random Noise



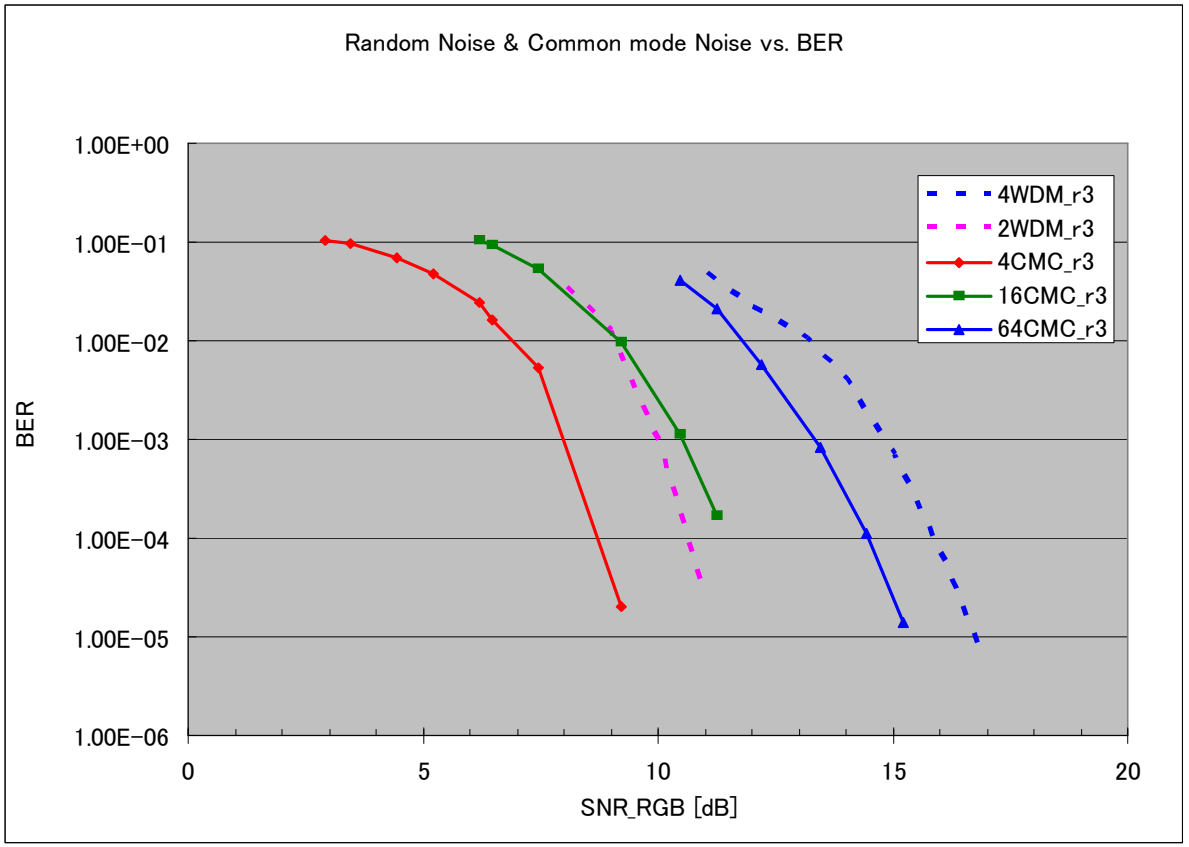

64CMC symbol positions （xy plane）




4WDM symbol positions （RGB space）

- 64CMC and 4WDM have same ability for transmitting speed ratio (6bits/symbol).
- CMC has 3dB lower BER performance in the random noise environment.

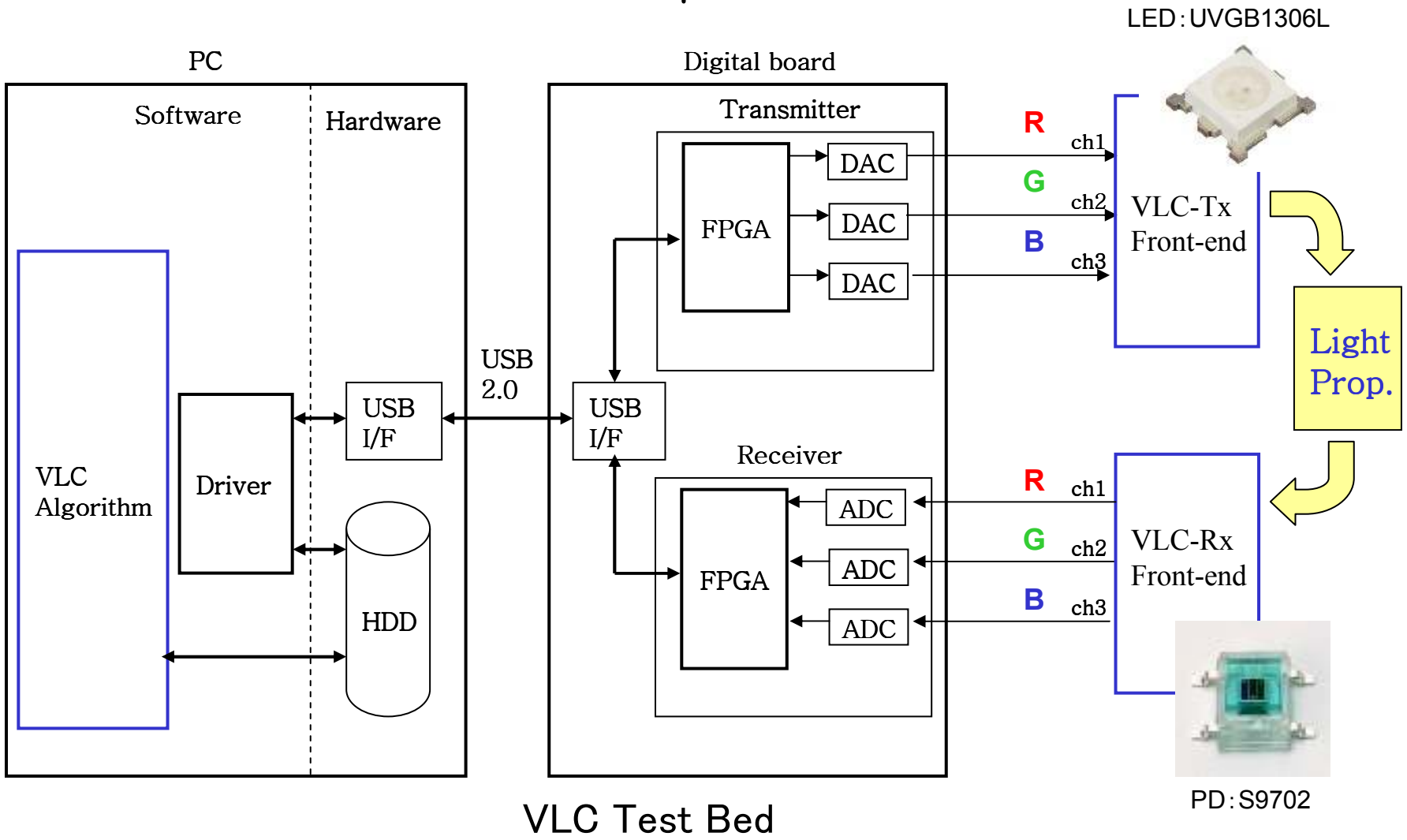
# BER performance with common mode noise




64CMC_r3：64points CMC（6bits/symbol) with Random Noise & +3dB Common mode Noise
4WDM_r3：4level/color WDM（6bits/symbol) with Random Noise & +3dB Common mode Noise

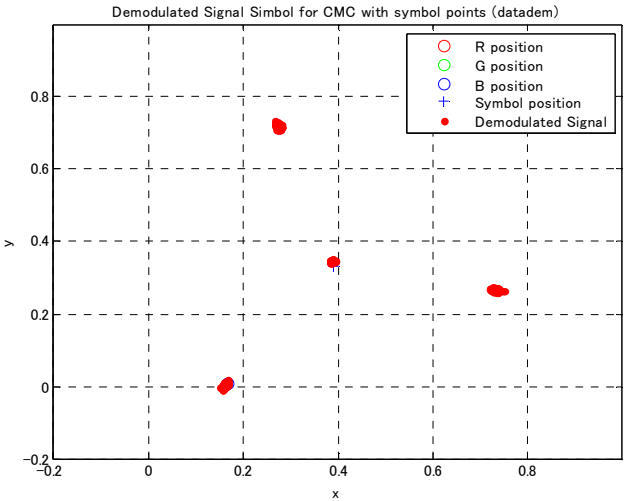
- 64CMC and 4WDM have same ability for transmitting speed ration.
- CMC has 1.5dB higher BER performance in the common mode noise environment.

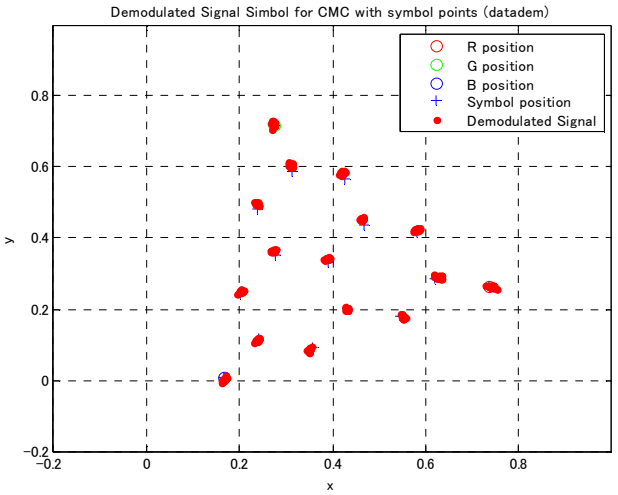
# CMC Experiment

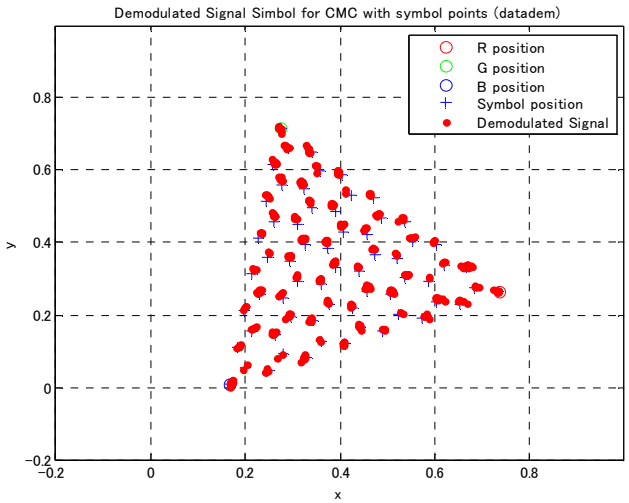



VLC Test Bed

# Experimental Results (2.5MHz/Symbol)



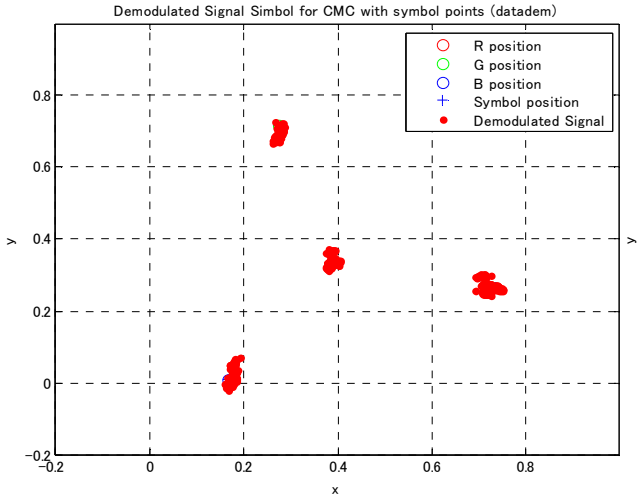




4CMC (5Mbps)
BER < $10^{-6}$

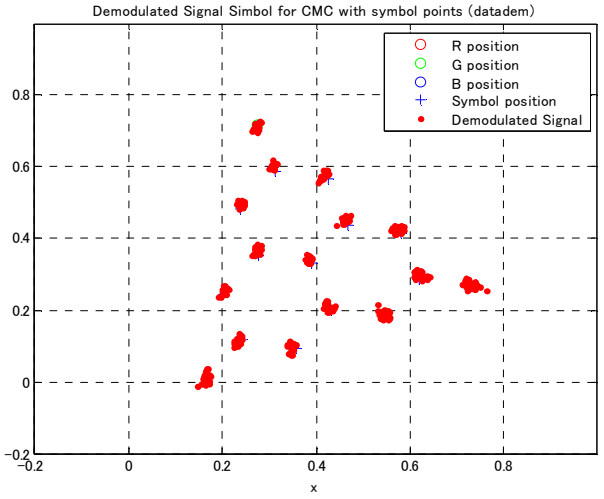
16CMC (10Mbps)
BER < $10^{-6}$

64CMC (15Mbps)
BER ≒ $10^{-4}$

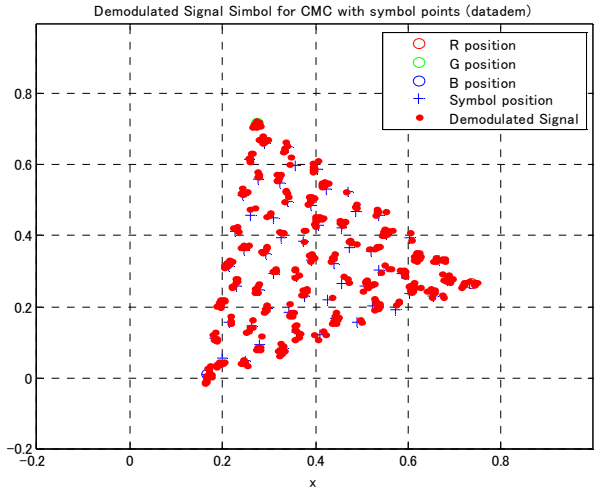
# Experimental Results (5MHz/Symbol)


4CMC (10Mbps)
BER < $10^{-6}$

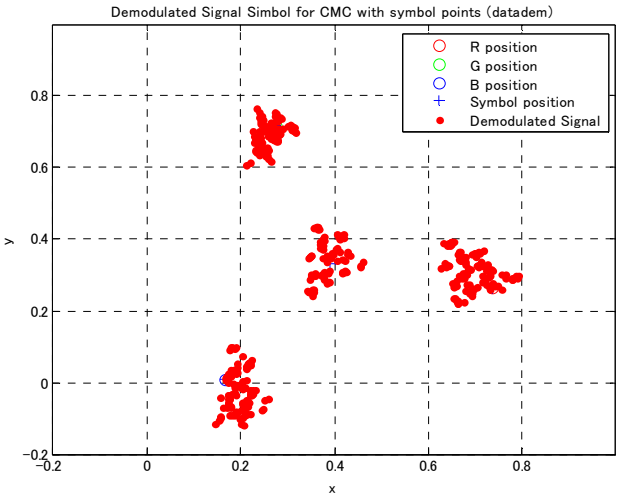




16CMC (20Mbps)
BER < $10^{-6}$

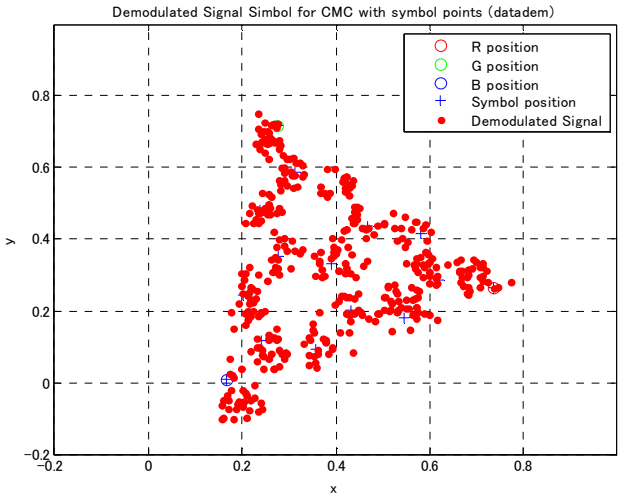




64CMC (30Mbps)
BER ≒ $10^{-3}$

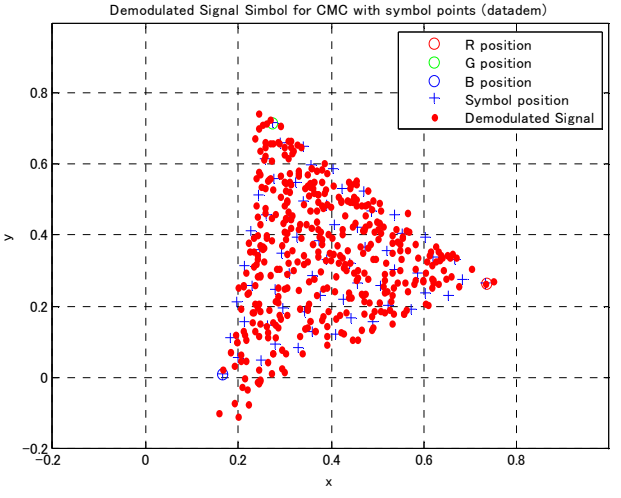
# Experimental Results (10MHz/Symbol)


4CMC (20Mbps)
BER < $10^{-6}$

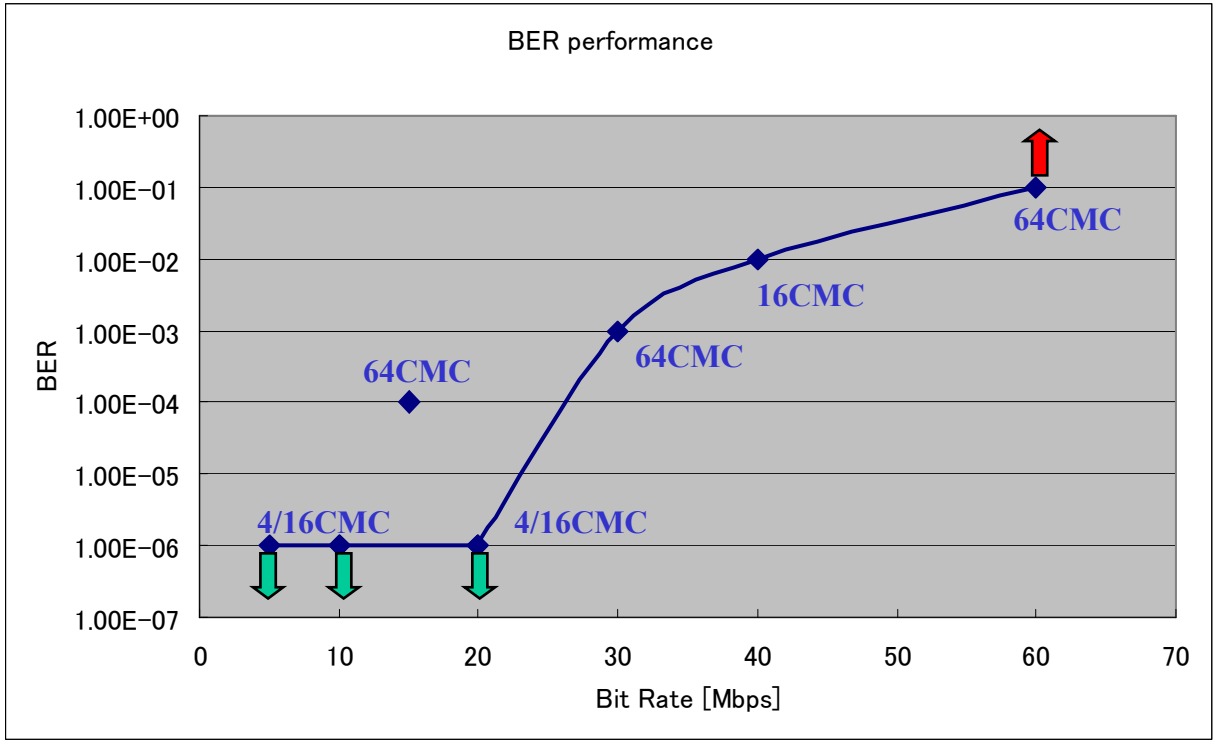




16CMC (40Mbps)
BER ≒ $10^{-2}$


64CMC (60Mbps)
BER > $10^{-1}$

# Experimental Results




4CMC：4points Color Multiplex Coding（2bits/symbol)
16CMC：16points Color Multiplex Coding（4bits/symbol)
64CMC：64points Color Multiplex Coding（6bits/symbol)

# Conclusion

- We proposed CMC as a new modulation scheme.
- CMC can provide more flexible VLC system than WDM.
- CMC has better performance than WDM in some case.
- We confirmed 20Mbps transmission on 16CMC.
- We can expect higher transmission speed by using the device (LED, PD) which has wider frequency band.

# Thank you for your attention!