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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]

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Color Multiplex Coding for VLC

2008.11.13

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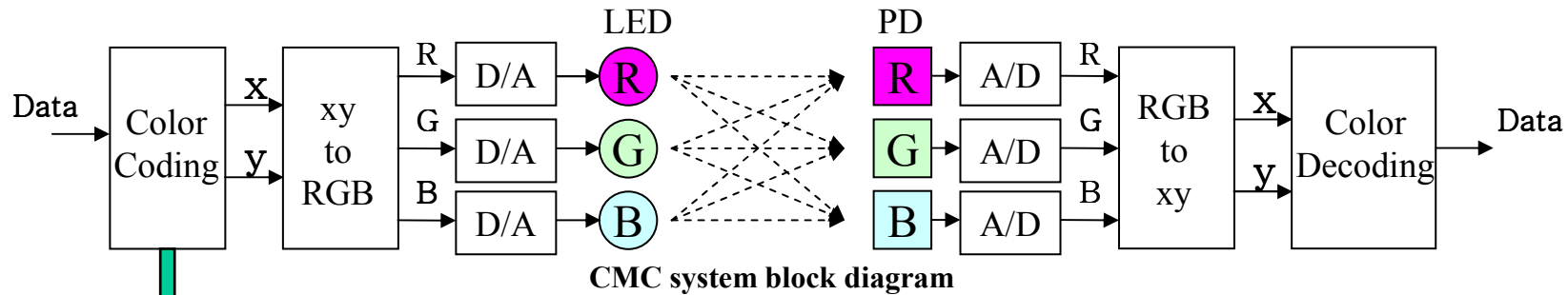
- Introduction
- What is CMC?
- Why CMC?
- CMC performance
 - Simulation Results
 - Experiment Results
- Conclusion

Introduction

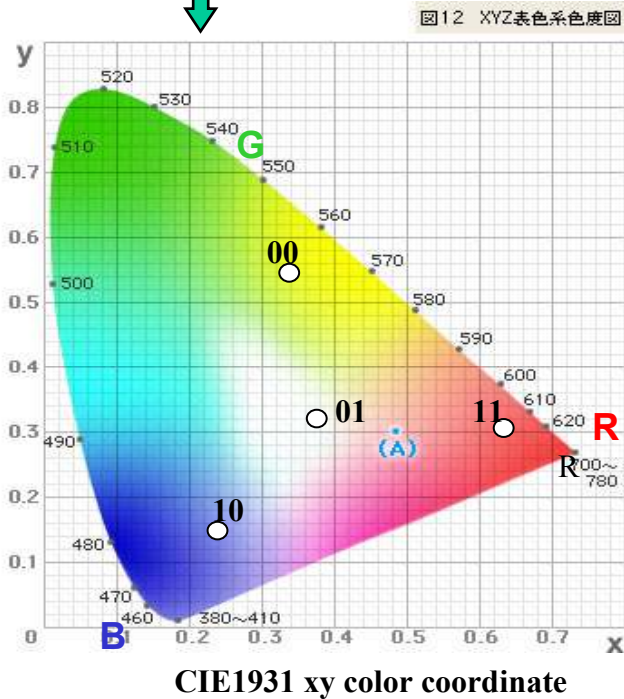
- **WDM (Wave Length Multiplex)** is a good scheme for realizing high speed transmissions.
- But the wave length and number have to be selected carefully, because those decide light devices (LED,PD) and the performance of VLC systems.
- WDM system depends on the light devices strongly.

- **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



- 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 .(R:700nm, G:546.1nm, B:435.8nm)

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

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

$$Z = 0.0565G + 5.5943B$$

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

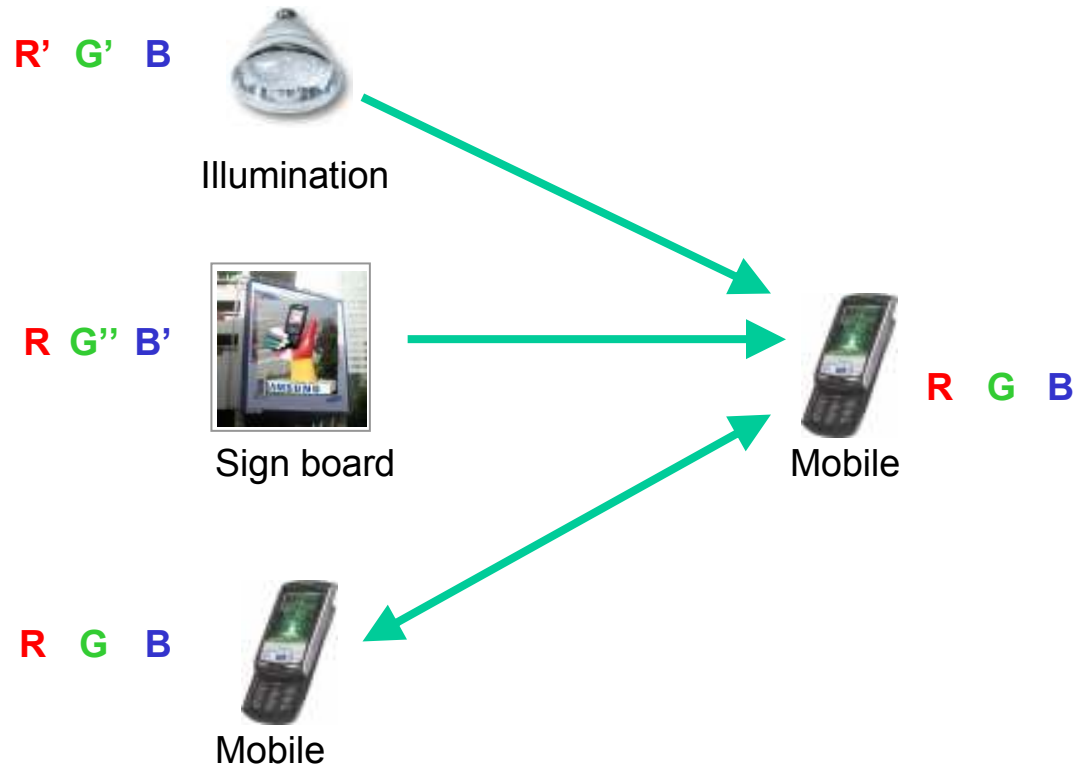
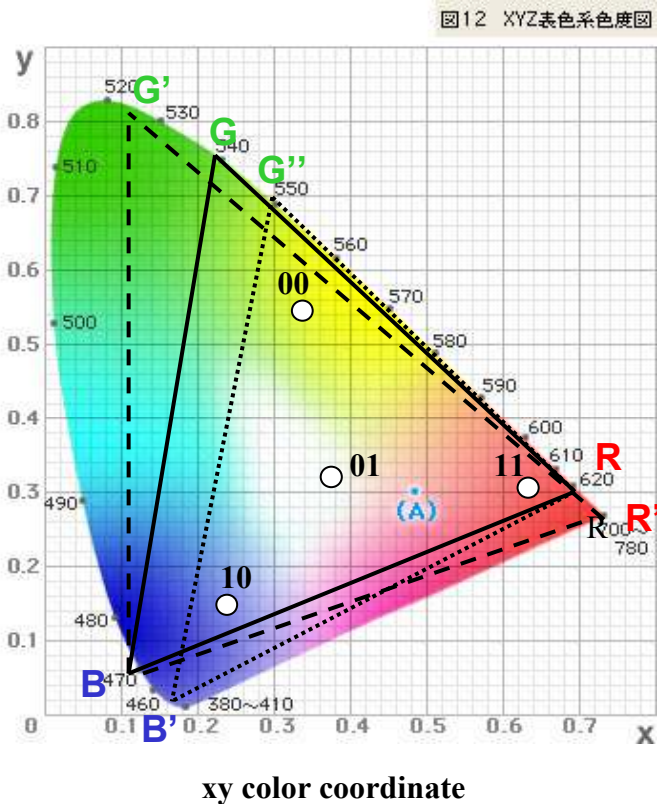
$$y = Y / (X + Y + Z)$$

- CMC symbols are provided as the visible colors which are made by RGB light sources.
- The information is transmitted as the intensity ratio among RGB.

Why CMC?

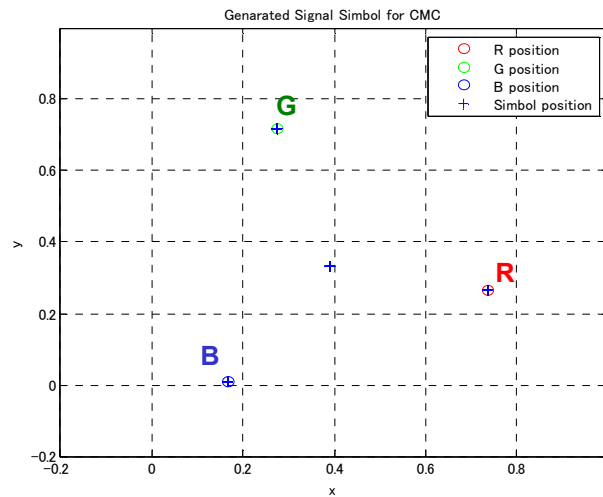
- WDM
 - Transmit data is distributed to RGB channels.
 - The channels are decided by the wave length and number.
 - Same wave length sources and detectors are required.
 - System flexibility is lower.
- CMC
 - Transmit data is allocated in the color coordinate plane.
 - The channels are decided by the color coordinate.
 - It doesn't depend on the wave length and number directly.
 - System flexibility is higher.

Why CMC?

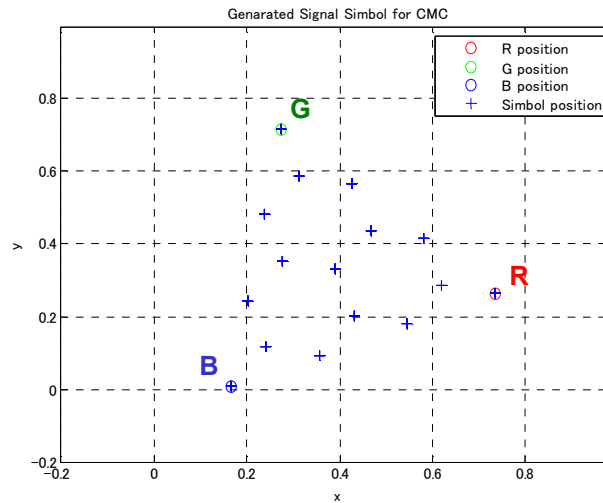


- Light source spectrum are different among the various devices.
- CMC symbols are produced by several light sources according to the color coordinate.
- CMC symbols can be reproduced by different light sensors.
- CMC guarantees the connectivity each device with xy color coordinate.
- CMC is better for VLC standardization with considering the connectivity among the different devices.

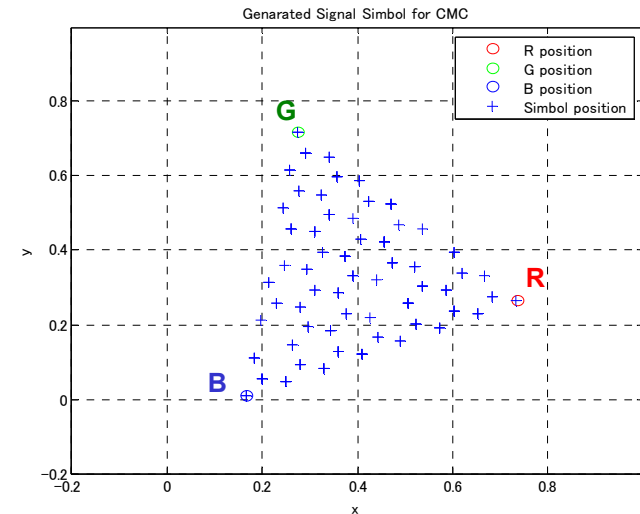
CMC simulation



4 CMC
(2bits/Symbol)



16 CMC
(4bits/Symbol)



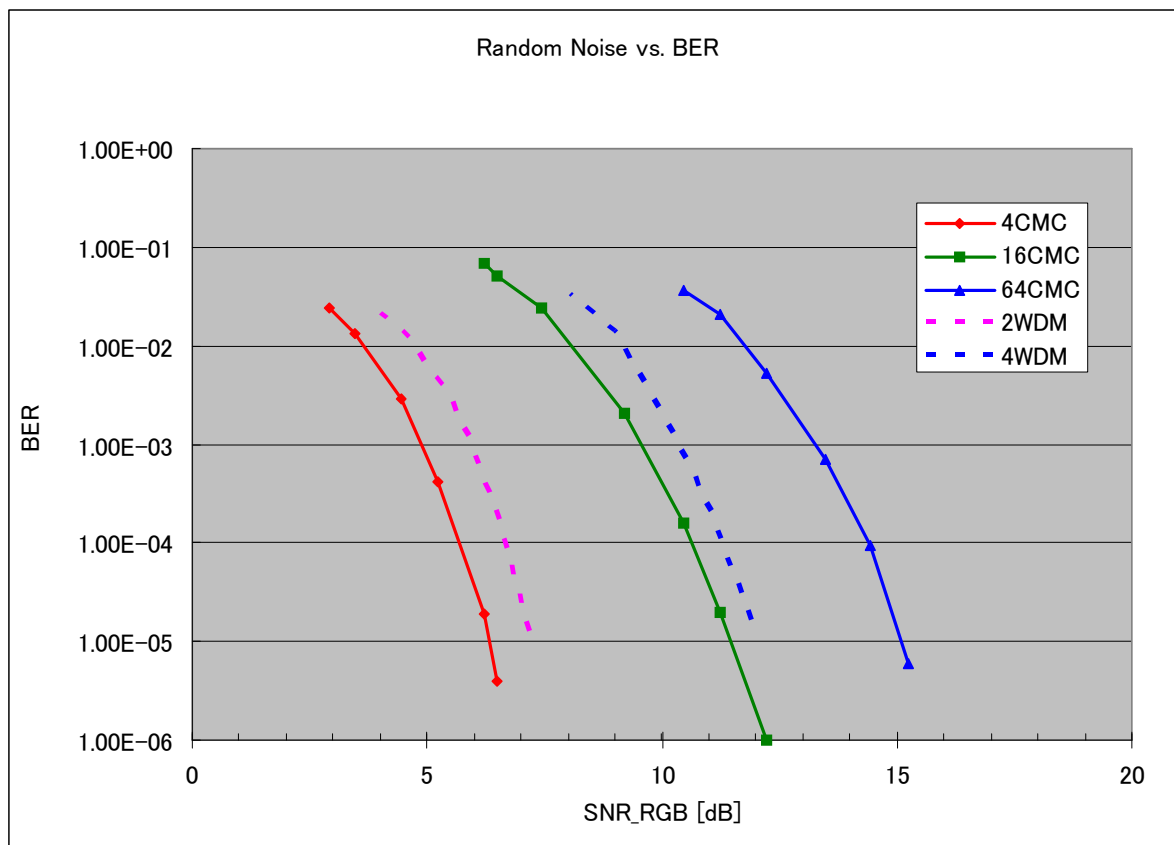
64 CMC
(6bits/Symbol)

Symbol position in xy color coordinate for CMC performance evaluation

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

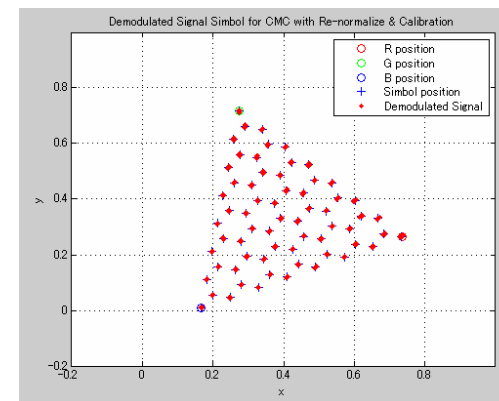
4CMC: 4points Color Multiplex Coding (2bits/symbol)
16CMC: 16points Color Multiplex Coding (4bits/symbol)
64CMC: 64points Color Multiplex Coding (6bits/symbol)

BER performance with random noise

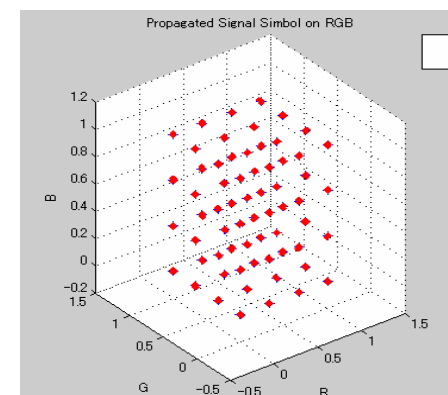


2WDM: 2level(On-Off)/color WDM (3bits/symbol) with Random Noise

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



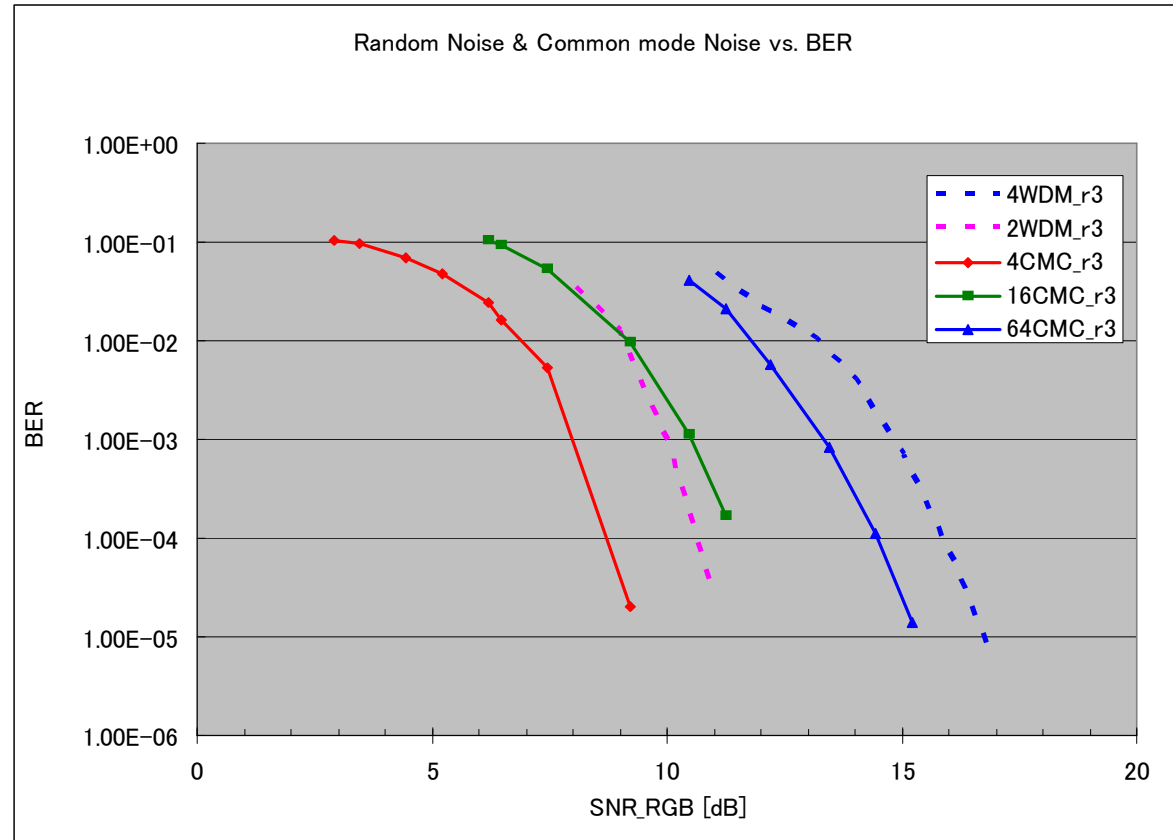
64CMC symbol positions (xy plane)



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.

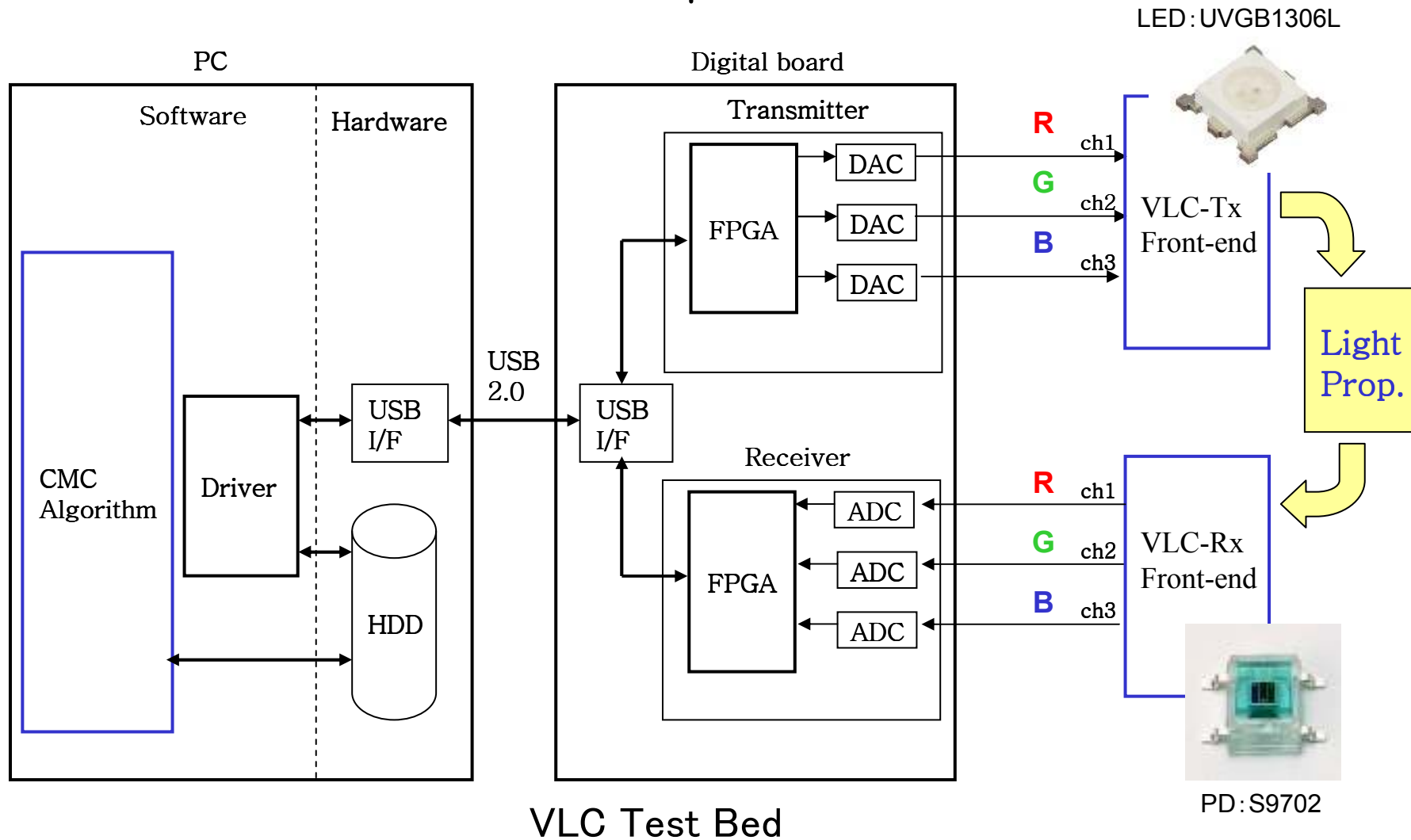
BER performance with common mode noise



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.

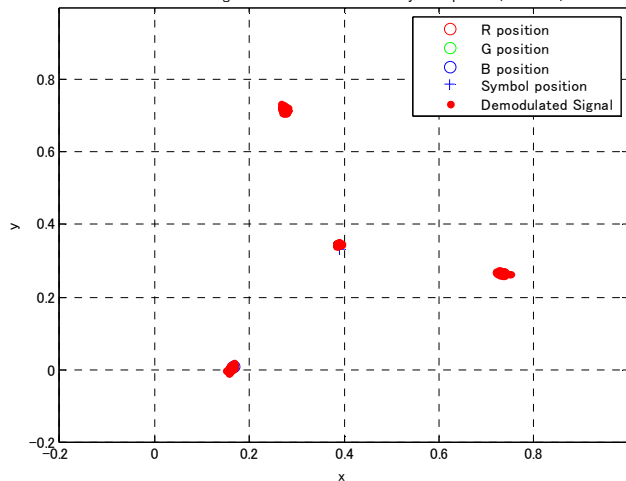
CMC Experiment



Experimental Results (2.5MHz/Symbol)



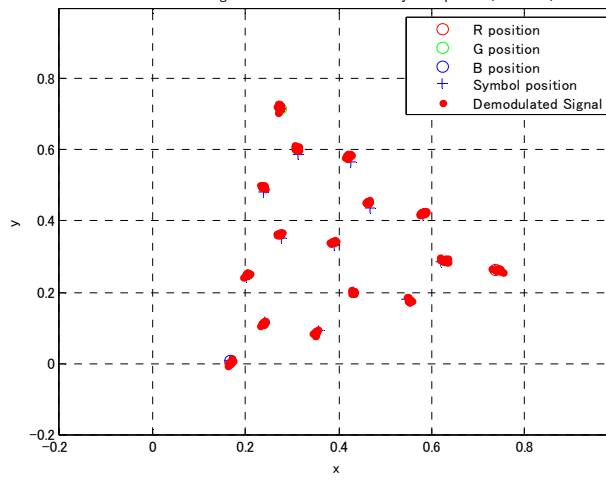
Demodulated Signal Symbol for CMC with symbol points (datadem)



4CMC (5Mbps)
BER <math>< 10^{-6}</math>



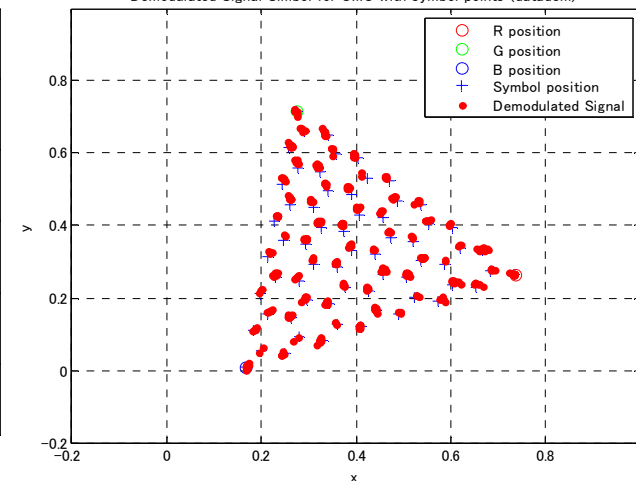
Demodulated Signal Symbol for CMC with symbol points (datadem)



16CMC (10Mbps)
BER <math>< 10^{-6}</math>



Demodulated Signal Symbol for CMC with symbol points (datadem)

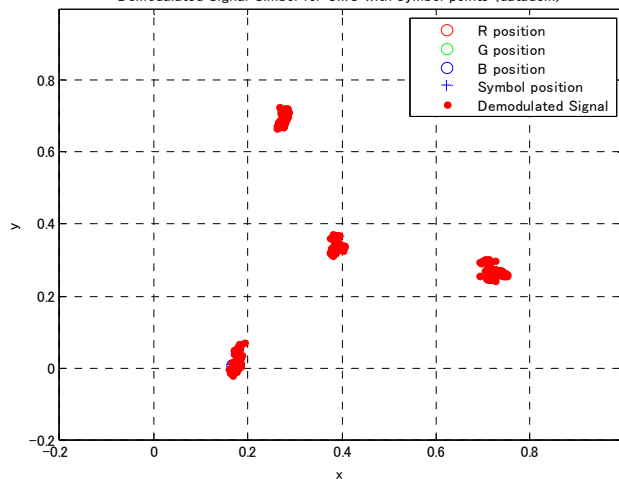


64CMC (15Mbps)
BER $\approx 10^{-4}$

Experimental Results (5MHz/Symbol)



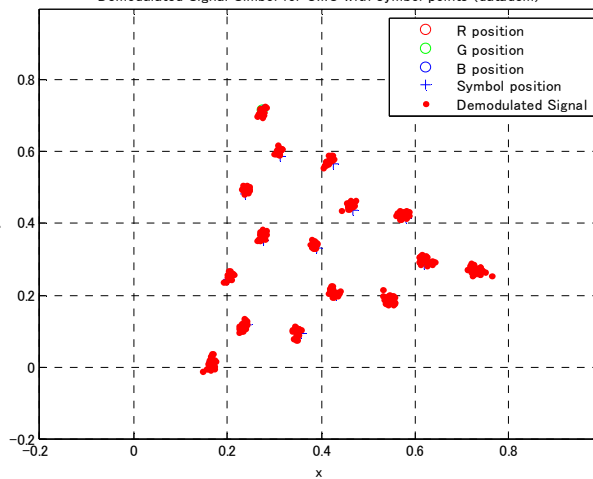
Demodulated Signal Symbol for CMC with symbol points (datadem)



4CMC (10Mbps)
BER <math>< 10^{-6}</math>



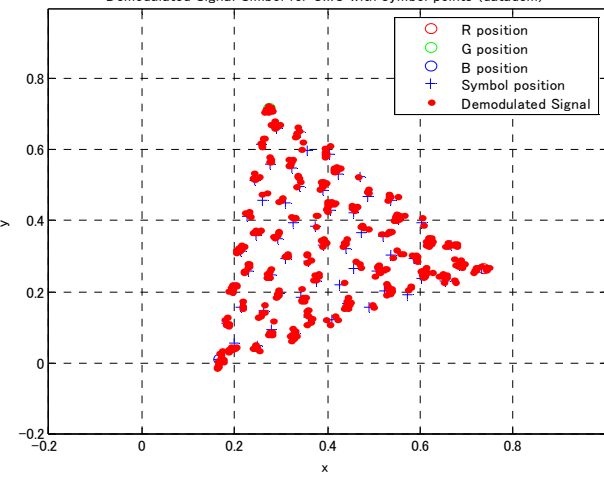
Demodulated Signal Symbol for CMC with symbol points (datadem)



16CMC (20Mbps)
BER <math>< 10^{-6}</math>

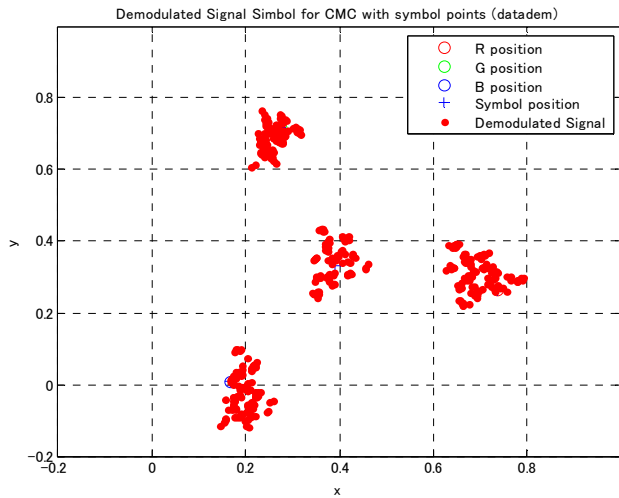


Demodulated Signal Symbol for CMC with symbol points (datadem)

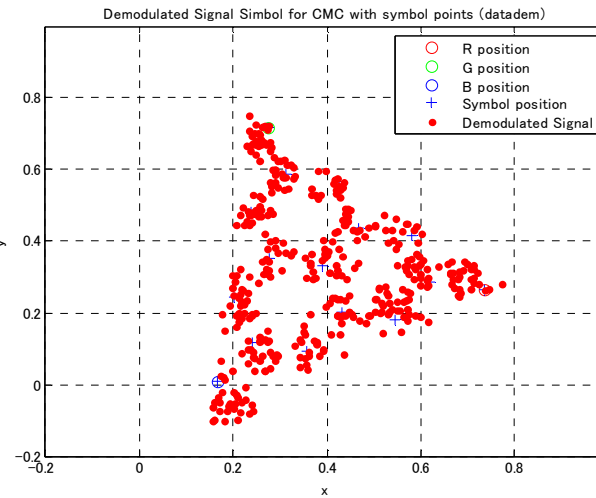


64CMC (30Mbps)
BER $\approx 10^{-3}$

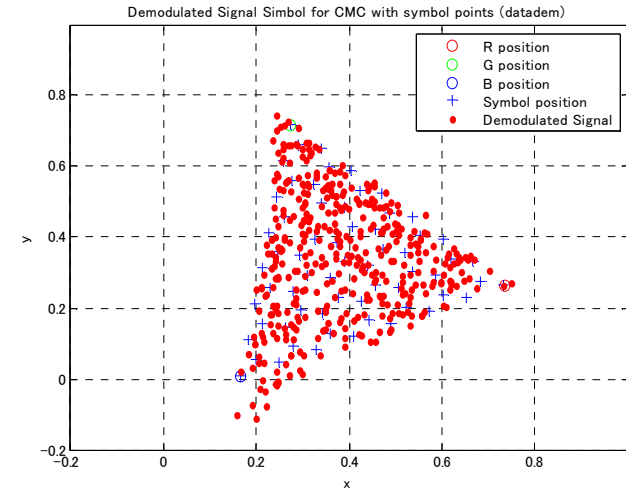
Experimental Results (10MHz/Symbol)



4CMC (20Mbps)
BER <math>< 10^{-6}</math>

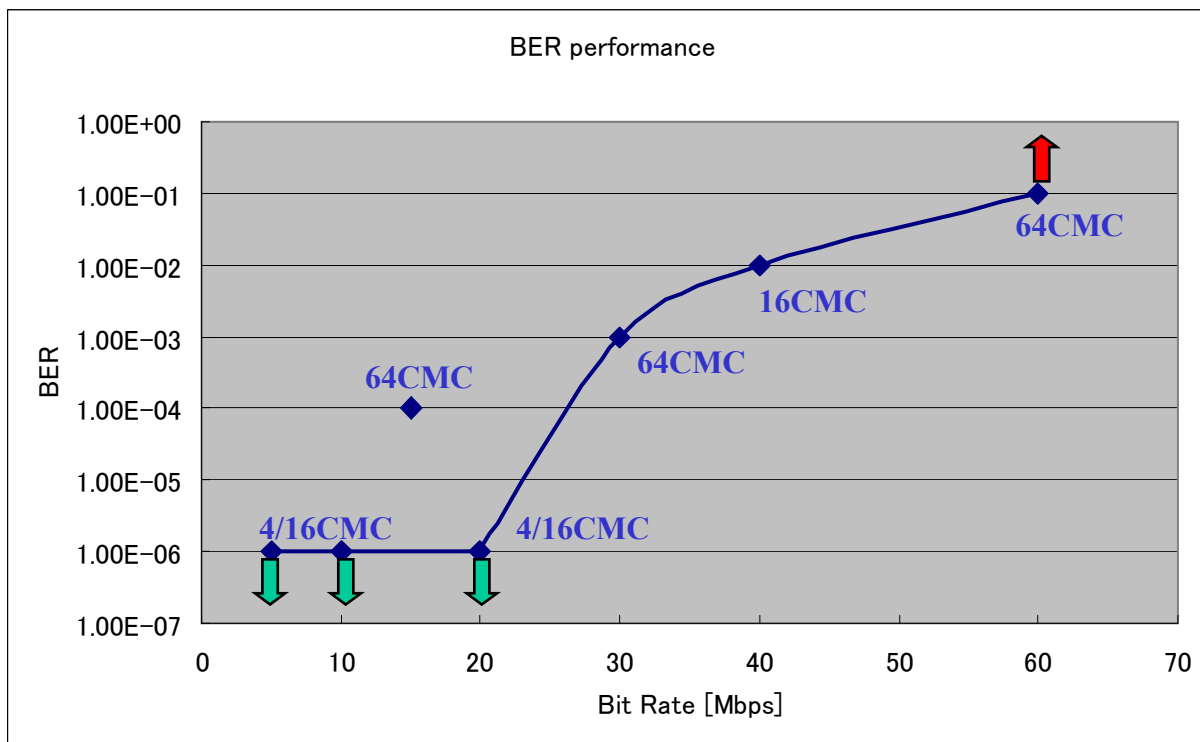


16CMC (40Mbps)
BER $\approx 10^{-2}$



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!