# An experimental scheme for cordwood color division multiplexing VLC system*

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In this paper, an experimental scheme for cordwood color division multiplexing (CDM) visible light communication (VLC) system is proposed. The principle and structure of the experimental scheme are described. Right angle prisms and band-pass filter are used to make the unit of the optical collector and splitter. We can add or subtract the unit as we need. The cordwood CDM-VLC system can also be effectively used as a model to accomplish color shift keying and color division duplexing. The experimental system provides a new way for researching VLC.

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Recently, light-emitting diode (LED) becomes a prevailing trend in illumination. The visible light communication (VLC) driven by LED is also gaining attention in academia and industry. The VLC is an optical wireless technology. The signal is modulated on fast flash visible light in this technology. VLC system can provide short-range, license-free, secure and electro-magnetic interference free link[1-3].

In order to highly increase the transmission speed and achieve high bandwidth efficiency, many methods, like amplitude modulation (AM), phase modulation (PM), frequency-division multiplexing (FDM) and time-division multiplexing (TDM), are researched in electro-magnetic wave communication and fiber optic communication. For the same reason, modulation and encoding methods are also researched in VLC[1-6].

Color division multiplexing (CDM) is a unique division multiplexing method in VLC. First, VLC is a technology which uses the visible light as the transmission medium instead of radio. CDM is a technique which divides the visible light waveband into a series of non-overlapping color wave sub-bands so that the total visible light waveband can be shared by many different color light signals. The white light is separated into some different monochromatic light waves in this method[5-9]. There is a guard interval between two adjoining sub-bands, so that the passbands of adjoining channels will not overlap, and the separated signals will not interfere with each other.

The experimental scheme designed in this paper can give us a direct and easy way to research CDM.

Fig.1(a) and (b) show the basic multiplexing schematic diagrams of transmitter and receiver, respectively. Each unit of the cordwood optical collector or splitter is combined with two right angle prisms. $TP_1$, $TP_2$, $TP_3$ and $TP_4$ are four right angle prisms. $TP_1$ and $TP_2$ make up an optical collector, and $TP_3$ and $TP_4$ make up an optical splitter.

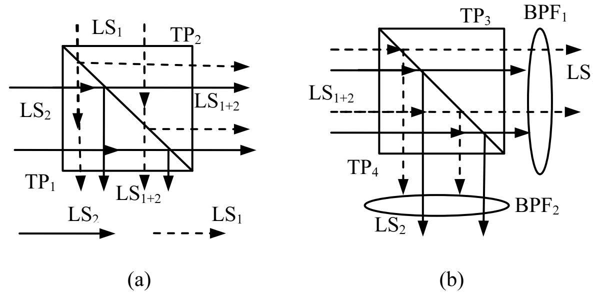


**Fig.1 Basic multiplexing schematic diagrams of (a) optical collector and (b) optical splitter**

$LS_1$ and $LS_2$ are two monochromatic light signals which are modulated in $X_1$ and $X_2$ wavelength ranges (unit: nm), respectively. $BPF_1$ and $BPF_2$ are two band-pass filters with the pass wavelength ranges of $X_1$ and $X_2$, respectively. $X_1$ wavelength range does not overlap with the $X_2$ wavelength range[10].

On the transmitter side, $LS_1$ and $LS_2$ are two separated optical signals which are modulated on two different color incident light waves. $LS_1$ goes into one leg of $TP_2$, then it reflects on the hypotenuse and goes out of the other leg of $TP_2$. At the same time, $LS_2$ goes into one leg of $TP_1$ and goes out of the same leg of $TP_2$. $LS_1$ and $LS_2$ mix and become hybrid light wave when they are going out of the

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transmitter.

On the receiver side, the hybrid light of $LS_1$, $LS_2$ and ambient light go into $TP_4$. Part of the hybrid light reflects and goes out of the leg of $TP_4$, while the other part of it goes out of the leg of $TP_3$.

There is a band-pass filter of $BPF_2$ on the leg of $TP_4$. Only the light in $X_2$ wavelength range can pass through $BPF_2$. $LS_2$ can pass through $BPF_2$, but $LS_1$ can't. $LS_1$ can pass through $BPF_1$, but $LS_2$ can't.

Photodetector behind the filter can receive the monochromatic light signal which is filtered. Then the signal can be processed by circuit.

Fig.2 shows two other examples of the optical collector in the cordwood CDM-VLC system, which are made by three units and four units of cordwood.

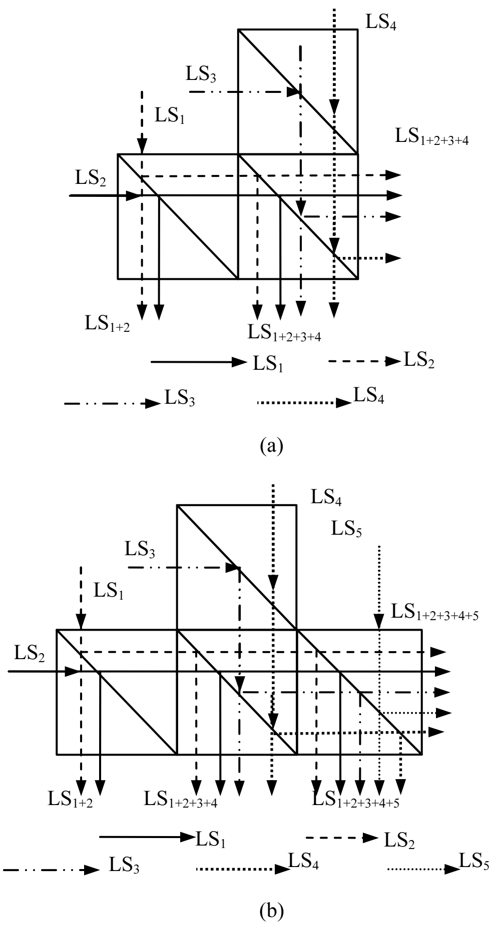



**Fig.2 Schematic diagrams of optical collectors made by (a) three units and (b) four units of cordwood**

In Fig.2, $LS_1$, $LS_2$, $LS_3$, $LS_4$ and $LS_5$ are five monochromatic light signals with different colors, whose wavelengths are non-overlapping. The monochromatic light signals enter the optical collector, and the hybrid light waves are output.

On the receiver side, the hybrid light waves go into the optical splitter, and are separated into a series of hybrid light waves. Filters on the output sides of the optical splitter can filter the unwanted light waves.

In order to prove the principle, a 2-CDM experiment setup is built as shown in Fig.3. Data1 and data2 are two channels of encoded data. Blue filter is a filter through which only the light with wavelengths from 600 nm to 700 nm can pass. Red filter is a filter through which only the light with wavelengths from 400 nm to 500 nm can pass. Fig.4 shows the transmittance spectra of blue filter and red filter. The guard interval in this test system is about 50 nm. WLED1 and WLED2 are two white LEDs. Photodiode1 (PD1) is used to receive the hybrid light mixed by optical collector. PD2 and PD3 are used to receive the light signals output from the optical splitter and filtered by the filter.

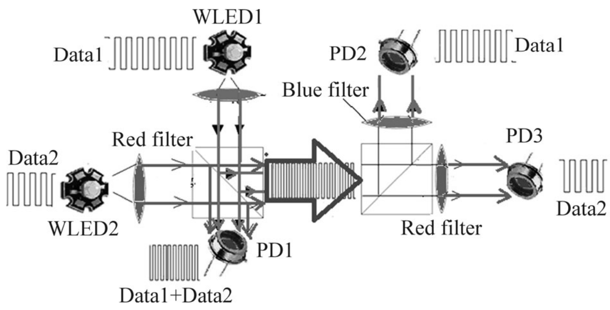



**Fig.3 Structure of the 2-CDM experiment apparatus**

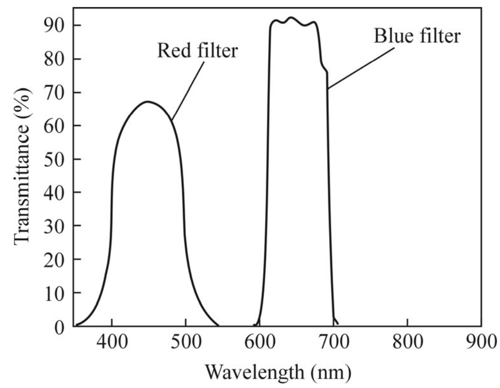



**Fig.4 Transmittance spectra of blue filter and red filter**

On the transmitter side, WLED1 is driven by electrical signal data1. The white light signal goes though the blue filter, and a blue light signal with wavelength range of 600–700 nm is output. WLED2 is driven by electrical signal data2. The white light signal goes though the red filter, and a red light signal with wavelength range of 400–500 nm is output. The red and the blue light signals enter the collector and become hybrid purple light signal.

On the receiver side, the hybrid purple light and ambient light go into optical splitter and are separated into two parts. Then the two incident light signals are filtered by two filters. PD1, PD2 and PD3 are used to receive the data light signals and convert them to electric signals. PD1 is used to receive data1 and data2, PD2 is used to receive data1, and PD3 is used to receive data2.

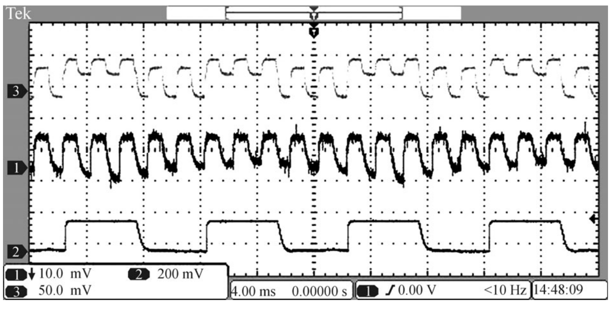
The 2-CDM experiment is finished in lab with 50–60 Hz low frequency interference light like lamp and monitor.

The test waveforms of the 2-CDM experimental apparatus are shown in Fig.5. The test signals are two square waves with different frequencies. The upper waveform from channel 3 (CH3) is the hybrid light received by PD1. The other two waveforms from channel 1 (CH1) and channel 2 (CH2) are the light signals received by PD3 and PD2, respectively. And two kinds of photodetectors are used in the test experiment. One is PIN photodiode BPX65 with the maximum response time of 12 ns, and the other is silicon photodiode HP202 with the maximum response time of 200 ns[10-15].

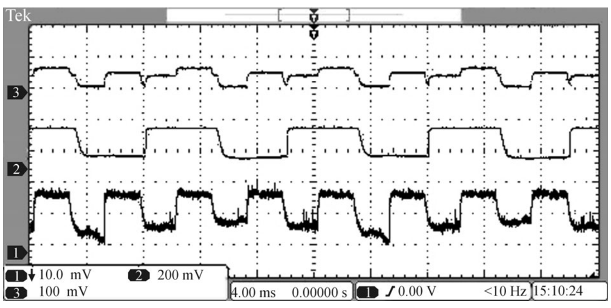
When two square waves with frequencies of 100 Hz and 500 Hz are input into the system, the waveforms of the output signals are shown in Fig.5(a), and the output signals are received by three HP202 PDs. In Fig.5(b), the input signals are two square waves with frequencies of 5 kHz and 10 kHz, and the output signals are received by three BPX65 PDs. In Fig.5(c), the input signals are two 1 kHz square waves in different phases, and the output signals are received by three HP202 PDs. In Fig.5(d), the input signals are two 500 kHz square waves in different phases, and the output signals are received by three BPX65 PDs.

It can be seen from Fig.5 that the two light signals data1 and data2 overlap and are received by the PD1 after the collector. And the overlapping signal can be received by PD2 and PD3 after it is filtered by blue filter and red filter on the receiver side.

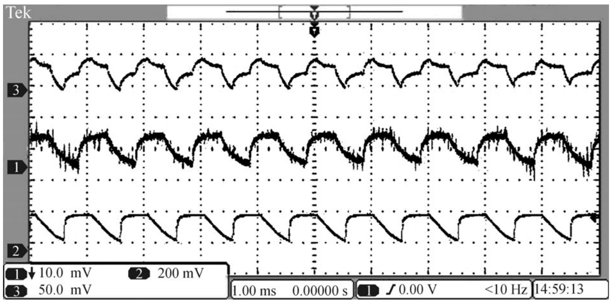
Corresponding light waves in the hybrid light signal can be successfully separated by filter and received by PD.



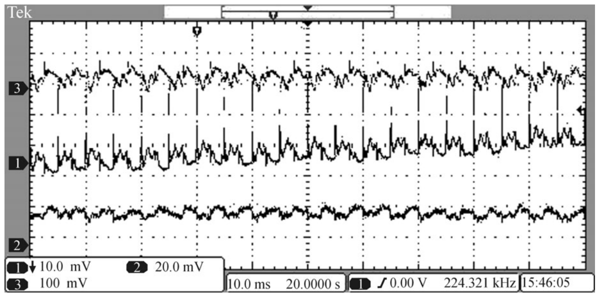

(a) Input signals with frequencies of 100 Hz and 500 Hz




(b) Input signals with frequencies of 5 kHz and 10 kHz




(c) Input signals with frequency of 1 kHz in different phases




(d) Input signals with frequency of 500 kHz in different phases

**Fig.5 Waveforms of output signals received by PD1, PD2 and PD3 in different situations**

Fig.3 and Fig.5 show an example of the cordwood CDM-VLC experimental system. It shows the multiplexing principle in the test. It can be known from the example that the experimental apparatus can add more units of cordwood with the corresponding filters in the optical collector and splitter, so that the CDM experiments with more than 2 channels can be carried out.

In conclusion, the principle and structure of the experimental apparatus are shown. The system can test an *n*-CDM experiment by adding more units of cordwood. Experimental apparatus and method described in this paper can be also used as a model to accomplish code shift keying (CSK) and some other modulations used in VLC. It is a transparent transmission method used in color modulation. A group of encoded data can be easily transported by the experimental apparatus.

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