Optical System design for high speed 2km free space optical communication

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ABSTRACT

The optical design and experimental results of a free space optical communication system operating at 2Gbps using 1550nm VCSEL were introduced. The optical transmitting system consists of three optical senders and an optical receiver and a photoelectric receiving circuit. An automatic tracking system was employed to eliminate the pointing error between communication terminals. Each optical sender was designed as Schmidt-Cassegrain antenna to collimate the laser beam. $\lambda/2$ plate and polarization beam splitter were used to decrease the interference of astigmatism and reflection. The optical receiver consists of a wave filter, dense-lines Fresnel lens and a photoelectric detector. The system's duplex communication tests showed that the data transmission rate can reach 2Gbps, error rate less than 10^{-9}, signal-to-noise ratio greater than 8 under the condition of clouds sky (attenuation coefficient is -16 dB/km) as the transmission length is 2000m, data carrier laser of 1550nm. The system had much higher speed rate comparing to other insertion system such as copper wire (1.5Mbps), electric cable (5Mbps), DSL (6Mbps per route).

Key Words: FSO, Optical sending antenna, Optical receiving antenna, Photoelectric receiving circuit

1. INTRODUCTION

Duplex wireless broadband communication using the carrier of laser to transmit data in space namely free space optical communication (FSO) raised large interests in communication field in 1960s. However, with the rapid development of optical fibre communication, the research of FSO was stagnant for the influence of weather and higher cost in 1970s. With the descending of the laser's cost and the development of high sensitivity receiver and advanced communication electron equipment, FSO has become a new branch of next generation optical communication in the future [1-3].

FSO consists of interstellar communication and ground surface communication according to the range of action. With the development of information times, the communication requirements of society in quality and quantity had become large. However, the satellite communication could not improve the transmit speed rate and capacity greatly in present for the limitation of microwave communication in wavelength, volume, weight and power consumption etc. The optical frequencies communication has huge potential in applying in high speed rate and large capacity in communication. And huge progresses had been obtained presently [4-13]. Contrasting to other broadband insertion system, FSO has many advantages as following: it has higher bandwidth than XDSL and Cable Modem, higher quality of anti-interference and secrecy than LMDS and Wi-Fi, and it has not the requirement of applying for the certificate of the wireless frequency channel. These advantages made it become the maximum means for solving the issue of "the last mile". In addition, FSO can be widely used for communication of bridging over barrier such as river and canyon, communication of temporary location, data circle of wireless base station, extension of city domain web, interconnect of corporations, backup of communication system and so on. In this paper, a new optical system is designed, with Schmidt-Cassegrain antenna as

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optical sender to collimate laser beam, and with a $\lambda/2$ plate and a polarization beam splitter to decrease the interference of astigmatism and reflection. A wave filter and Fresnel lens and a photoelectric receiving circuit were used to receive and dispose the signal.

2. OPTICAL SIGNAL SENDER ANTENNA

In FSO sending system, because of laser divergence, laser spot will become larger with the increase of transmission distance. For example, if the system has the characteristic of laser divergence of 1mrad, the transmission distance of 1km, the laser spot's diameter will become 1m on the object plane. There will be a great loss of the optical energy if laser spot's diameter is larger than that of the receiver. In addition, the background light, reflex light from optical lens will affect signal seriously. All these negative factors will make it difficult to communicate in free space. To exclude these negative factors, we designed a sending system as in Fig.1, which is mainly composed of a Schmidt-Cassegrain antenna, a polarization beam splitter and a $\lambda/2$ plate. The antenna's main reflex plane's right focus coincides with the second reflex plane's left focus. A polarization beam splitter and a half-wave plate were used to prevent S polarized light to reflect to the Schmidt-Cassegrain antenna to interfere the signal.

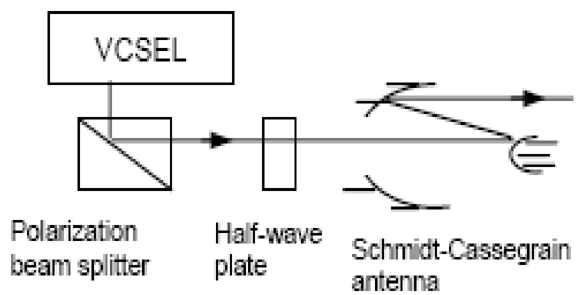


Fig.1 Optical signal Sender antenna

The optical antenna is the most important part in FSO. In our system, a reflex Schmidt-Cassegrain antenna was used as the optical sending antenna, in which the focus length of the main reflex plane and the second reflex plane are f_1 and f_2 respectively. When the laser transmission in the atmosphere, the laser beam's far field angle of divergence has the following form:

$$\theta = \lim_{z\to\infty} \frac{2\omega(z)}{Mz} = \frac{2\lambda}{M\pi\omega_0} \qquad (1)$$

where ω_0 is the girdling of Gauss beam , M is an enlargement factor of the Schmidt-Cassegrain antenna, and $M = f_1 / f_2$

3. OPTICAL RECEIVER MODULE

Optical receiver module mainly consists of optical receiving antenna and photoelectric receiving circuit. To eliminate the noise and other astigmatism signal, the optical receiving antenna was composed of a wave filter, a Fresnel lens. Through the receiving antenna, the optical signal was focused to the electrophotonic detector and then transferred to electric signal. The microgroove Fresnel lens with screw spacing interval of 0.278mm, diameter of 100mm and material of PMMA of refractive index of 1.49, Abbe number of 57.8 and transmissivity of 90%.

Photoelectric receiving circuit consists of photoelectric conversion circuit, difference amplifier, and automatic gain controller, comparing and shaping circuit as shown in Fig.2. APD can transfer the received weak optical signal into electric signal. However, as Photoelectric conversion circuit consists of avalanche silicon diode (APD) and transimpedance providing the high receiving sensitivity and long distance communication, APD suffered from the high offset electric voltage. To ensure APD working in optimum multiplication state and decreasing the error rate, the sensing circuit was satisfied the function as following:

$$\mathrm{U} = 744\ \mathrm{mV} + (\mathrm{T} \times 11.9\mathrm{mV}/{}^{\circ}C) \qquad (2)$$

U and T are the sensing circuit's voltage and system's temperature respectively.

APD transferred the received optical signal into electric signal and sent it to transimpedance amplifier, and then the electric signal was transferred into two-way electric voltage signal with mutual phase reversal. After difference amplifying and automatic gain by the difference amplifier and gain-controlled amplifier, the two-way electric voltage signal were sent to comparison and shaping module. The RMS values of the output signal of the gain-controller were detected and feed backed to gain-controller for controlling the magnification times and stabilizing the RMS on a certain value. The gain-controller and RMS detection circuit working together as the automatic gain controlling circuit can stabilize the value of output signal on the set value by controlling the magnification times automatically from 0 to 20dB. Finally, the mutual phase reversal output signals with the format of PECL electric level were sent to the optical send-receiver module.

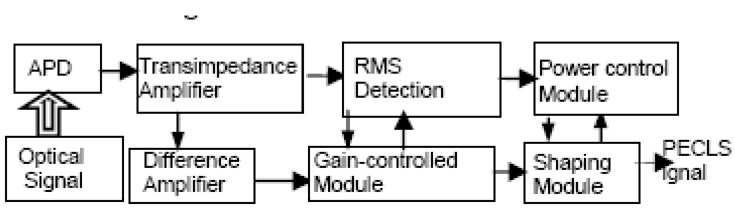


Fig.2 Optoelectronic receiver circuit setup

4. LASER TRANSMITTING SYSTEM

Laser transmitting system circuit consists of laser transmitter, laser driver and optical transmitting antenna. Comparing to the conventional semiconductor emitting laser(EEL), the vertical cavity semiconductor emitting laser(VCSEL), its circle thin beam has the advantages of smaller far field angle of divergence and easier to couple into optical fibre. The 1550nm VCSEL laser (Infineon Company, Germany) was used as the data carrier laser. The VCSEL's primary parameters and their relations are shown in Fig.3. In section of Fig.3 reveals it has the characteristics of working current of 12mA, threshold current of 3mA, average modulated current of 8mA, average optical power greater than 2mW, temperature coefficient of -0.15%/℃. In addition, the direct current offset current and signal modulated current are needed for direct modulating laser diodes.

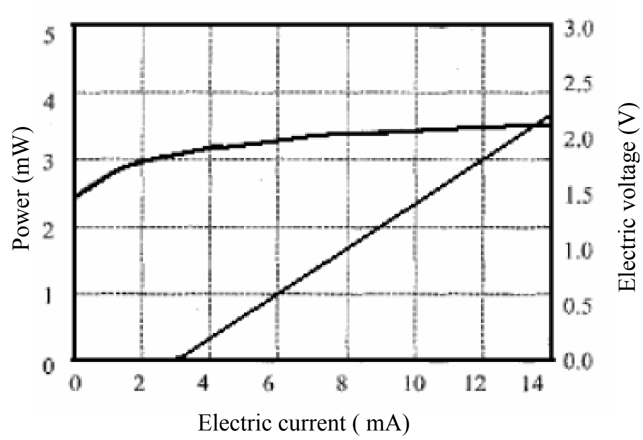


Fig.3 Power-current-voltage curve of VCSEL

In this system, the optical signal from the optical fibre was transferred into electric signal with the format of PECL electrical level by using the optical fibre sender-receiver module with the wavelength of 1550nm, speed rate of 2Gbps. Three-way PECL electrical level was send to the VCSEL driver circuit by using the PECL to 3PECL module. And then the VCSEL driver circuit drives the VCSEL laser to radiate the direct modulated optical signal to the optical receiver. To obtain the appropriated laser power in different communication distance and weather condition, the laser power control circuit has 5-step adjust and control function of -30dB, -20dB, -10dB, -5dB, 0dB corresponding to communication distance of less than 200m, 200 to 400m, 400 to 600m, 600 to 800m and 800 to 2000m respectively.

Optical transmitter antenna mainly consists of sighting telescope and laser collimating system with three optical extender lenses. The VCSEL laser source with angle of divergence of 20 degree lies on the focus of the transmitter lens. To couple the signal light of the VCSEL into transmitter lens entirely, the transmitter lens' parameters must meet the function as following shows:

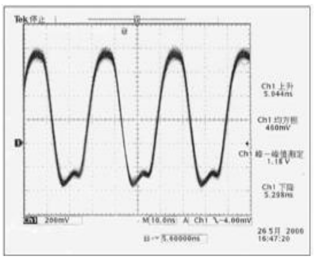
$$D/2 > L_f \times \tan 10^\circ \qquad (3)$$

D and L_f represent the diameter and focal distance of the transmitter lens respectively.

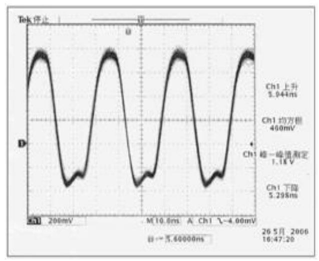
To decrease system's chromatic aberration, the transmitter lens was composed of three plane convex lens with the focal distance of 100mm, diameter of 40mm, thickness of 3mm and material of K9 glass for reducing the influence of temperature changing of the environment. The K9 glass with small Abbe number can decrease the signal's attenuation causing by the shifting of light source's peak wavelength. To decrease the light beam's distortion, shifting and flashing causing by the strong wind and rain, the transmitter lens has the angle of divergence of 2mrad, which can form a rather large beam spot for optical receiver. In addition, the transmitting of three-way laser simultaneous and locating the optical receiver into the overprinting area can increase the total output power and smooth the communication.

5. EXPERIMENT RESULTS AND ANALYSIS

The FSO system consists of two optical send-receivers with both-way communication capability and optical fibre module data interface. The distance of the two optical send-receivers is adjustable in 2.1km. In experiment, the standard test signal from the error code instrument was sent to optical transmitter to radiating on the transmitting terminal. The signal received by the optical receiver on the receiver terminal was return transferred to the optical receiver on the transmitting terminal. And the signal received by the optical receiver terminal was sent to error instrument. And then the circulation circuit testing system formed. The analog signals received by the transmitting and receiver terminal were real-time monitored by oscillograph and the error rate was calculated by the error code instrument. Analog signal waveforms detected by oscillograph under the condition of temperature of 28 degree, moisture percentage of 60% and overcast (modulus decay of -15dB/km) were shown in Fig.4. Fig.4(a), (b), (c), (d), (e) and (f) were represented the analog signals waveform of the original signal waveform, the received signals waveform by the optical receiver on the distance of 300m, 700m, 1750m, 2000m and the noise waveform of the receiver respectively. It showed that the signal waveform held the uniform shaping as the transmission length was 2000m.



(a)



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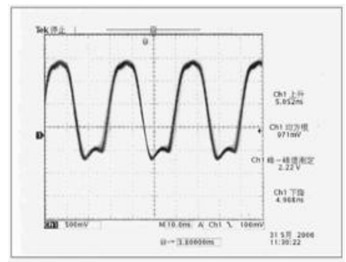

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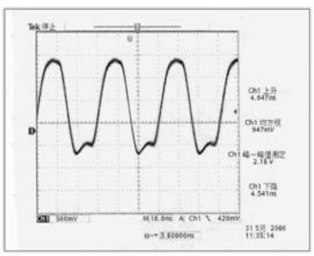
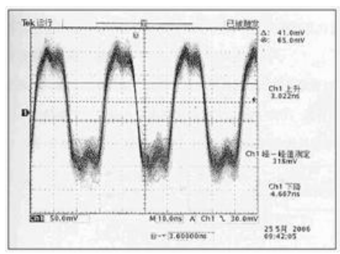
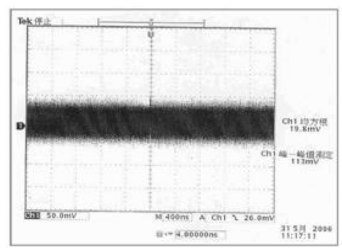


(d)



(e)



(f)

Fig.4. Analog signal waveform detected by oscillograph.

(a) Original transmission signal, (b) Received signal of the transmission length of 300m, (c) Received signal of the transmission length of 700m, (d) Received signal of the transmission length of 1750m, (e) Received signal of the transmission length of 2000m,(f) Noise waveform of the receiver

6. CONCLUSION

An optical system of free Space Optical Communication system using for the issue of “The Last Mile” was introduced. Three-way laser transmitting system mainly consists of VCSEL laser transmitter, laser driver, optical transmitting antenna and sighting telescope. Laser receiver system mainly consists of microgroove Fresnel lens receiver antenna, APD, difference amplifier, automatic gain-controller and comparison and shaping circuit. The duplex communication experimental results showed that the data transmission speed rate can reach 2Gbps, error rate less than 10^{-9}, signal-to-noise ratio greater than 8 under the condition of overcast sky (attenuation coefficient is -15 dB/km) as the transmission length is 2000m, data carrier laser of 1550nm. The system has much higher speed rate comparing to other insertion system such as copper wire (1.5Mbps), electric cable (5Mbps), DSL (6Mbps per route). It can be applied to connect the high-speed rate trunk optical fibre net to the high-speed rate user circuit, namely “the last mile issue”.

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