Photonic envelope detection and fiber transmission of 24 GHz IR-UWB signal based on phase modulation*

YIN Xiao-li (尹霄丽), **HAN Jing-jing** (韩晶晶)**, **XU Can** (徐灿), **HAO Ji** (郝季), **XIN Xiang-jun** (忻向军), **and LI Li** (李莉)

State Key Laboratory of Information Photonics and Optical Communications, School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China

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A novel scheme for photonic envelope detection and fiber transmission of 24 GHz impulse radio ultra-wideband (IR-UWB) signal is proposed based on phase modulator (PM). In the system, an optics assisted envelope detection unit (OAEDU) is used for filtering one of the first sidebands at the output of PM, then this narrow band optical signal transfers over single-mode fiber (SMF), and the envelope of 24 GHz IR-UWB signal is obtained after photodetection (PD) and low pass filter (LPF). The numerical simulation results show that the combination of PM and OAEDU can alleviate the fiber chromatic dispersion (CD) effectively. The proposed system may provide a simple and cost-effective solution for IR-UWB receiver.

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Ultra-wideband (UWB) radio technology has been considered as a promising candidate for short-distance high-speed wireless communications and senor networks[1,2]. The impulse radio UWB (IR-UWB) is attractive due to the carrier-free advantage and better pass-through feature[3]. IR-UWB in 24 GHz band is an effective solution for high-resolution short-range radar (SRR) and precise localization. The 24 GHz IR-UWB signal should comply with the Federal Communications Commission (FCC) rules[4], and its spectral density is regulated to be less than –41.3 dBm/MHz. IR-UWB is limited to the application in short distance which is around ten of meters because of its low power density. To increase the coverage and the availability of connecting to different networks, IR-UWB over fiber system has been proposed[5,6].

In the previous study[7], we have proposed a novel scheme to generate 24 GHz IR-UWB signals using optical pulse shapers. The 24 GHz-band IR-UWB signals have the characteristics of narrow pulse width and low signal strength, and they are very difficult to be sampled at the correct time. Recently, various electric and photonic detection approaches have been demonstrated to implement the IR-UWB detection[8-12]. Coherent and non-coherent detection techniques have been investigated in electrical domain[8-10], but these techniques require both the photoelectric conversion units and electric envelope detection devices, which will increase the system complexity. Compared with electric detection techniques, photonic detection techniques have been researched due to their inherent advantages, such as large bandwidth, small size and immunity to electromagnetic interference[11,12]. However, both techniques employ Mach-Zehnder electro-optical modulator (MZM), which not only require bias control to maintain a stable optical operating point but also include the relative time delay control to generate the pull-push signal.

In this paper, we propose a novel photonic envelope detection and fiber transmission scheme for 24 GHz IR-UWB signals using phase modulator (PM). As we all know, the performance of an IR-UWB over fiber system would be affected by chromatic dispersion (CD). The optics assisted envelope detection unit (OAEDU) and the PM are used to generate the narrow band optical envelope signal, which can be more tolerant to the CD. Furthermore, the proposed scheme has simple structure and high stability.

The schematic diagram of the IR-UWB optical communication system is demonstrated in Fig.1. The 24 GHz IR-UWB signals are received by the wireless access point (WAP) and transmitted to the central station (CS) via fiber communication network. The narrow band optical generation technique is of great importance in our proposed scheme. The OAEDU is used in WAP to generate narrow band optical envelope signal as shown in Fig.2. This narrow band optical envelope signal is amplified by erbium-doped optical fiber amplifier (EDFA), and then transmitted through a single-mode fiber (SMF) to the CS. The envelope of 24 GHz IR-UWB signal is obtained after photodetection (PD) and low pass filter (LPF) in the CS.

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** E-mail: han_ct@163.com

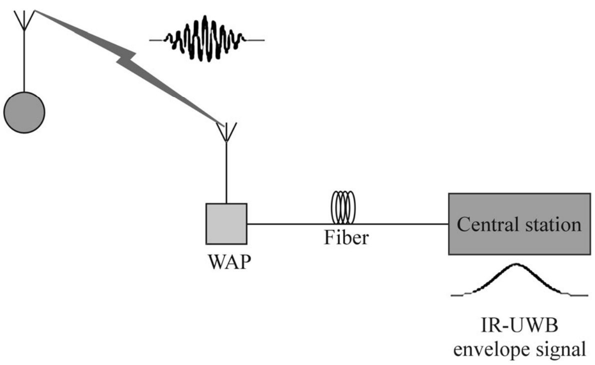


Fig.1 Schematic diagram of the IR-UWB optical communication system

In Fig.2, a narrow band continuous wave from laser diode expressed as $E_{in}(t)=A_c\exp(j\omega_c t)$ is modulated by an $LiNbO_3$ PM, where A_c and ω_c are the amplitude and angular frequency, respectively.

The output of PM can be expressed as

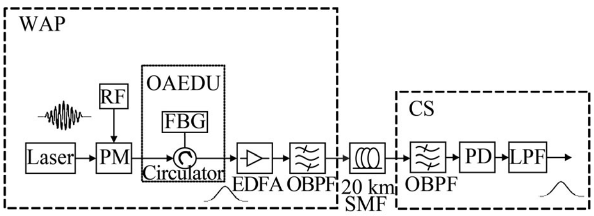
$$E_{PM}(t)=\alpha_{PM}A_c\exp(j\omega_c t)\exp\left[j\frac{\pi}{V_{\pi,PM}}V_{rf}(t)\right], \quad (1)$$

where $V_{\pi,PM}$ is the half-wave voltage of PM, α_{PM} is the optical loss of PM, and $V_{rf}(t)$ is the 24 GHz IR-UWB signal, which can be roughly modeled by a bandpass signal as[7]

$$V_{rf}(t)=A_m s_B(t)\cos(\omega_m t), \quad (2)$$

where A_m is the amplitude, $s_B(t)$ is the equivalent baseband signal, and ω_m is the center frequency of the IR-UWB signal. So the output of PM can be further expressed as

$$E_{PM}(t)=\alpha_{PM}A_c\exp(j\omega_c t)\times$$
$$\exp\left[j\frac{\pi}{V_{\pi,PM}}A_m s_B(t)\cos(\omega_m t)\right]. \quad (3)$$



RF: 24 GHz IR-UWB signal; PM: phase modulator; EDFA: erbium-doped optical fiber amplifier; OBPF: optical band-pass filter; SMF: single-mode fiber; FBG: fiber Bragg grating; PD: photodetector; LPF: low pass filter

Fig.2 Schematic diagram of the photonic envelope detection and fiber transmission system using OAEDU in WAP

Taking the Bessel series expansion, Eq.(3) can be written as

$$E_{PM}(t)=\alpha_{PM}A_c\exp(j\omega_c t)\times$$
$$\{J_0(\phi_{PM})s_B(t)+$$
$$2\sum_{n=1}^{\infty}(-1)^n J_{2n}(\phi_{PM})s_B(t)\cos(2n\omega_m t)+$$
$$2j\sum_{n=0}^{\infty}(-1)^n J_{2n+1}(\phi_{PM})s_B(t)\cos\left[(2n+1)\omega_m t\right]\Big\}, \quad (4)$$

where $\phi_{PM}=\frac{\pi A_m}{V_{\pi,PM}}$.

For $n=0$, the two first-order sidebands of Eq.(4) can be written as

$$E_{PM\_1}(t)=2j\alpha_{PM}A_c J_1(\phi_{PM})s_B(t)\cos(\omega_m t)\exp(j\omega_c t)=$$
$$j\alpha_{PM}A_c J_1(\phi_{PM})s_B(t)\exp(j\omega_c t+j\omega_m t)+$$
$$j\alpha_{PM}A_c J_1(\phi_{PM})s_B(t)\exp(j\omega_c t-j\omega_m t). \quad (5)$$

An OAEDU is used after the PM to filter the upper term of the two first-order sidebands, and the narrow band optical envelope signal can be obtained. The OAEDU output in the electrical field is

$$E_{PM\_2}(t)=j\alpha_{PM}A_c J_1(\phi_{PM})s_B(t)\exp(j\omega_c t+j\omega_m t). \quad (6)$$

This narrow band optical envelope signal is sent to EDFA and transmitted over 20 km in SMF, and the output signal is

$$E_{PM\_3}(t)=jG\alpha_{PM}A_c J_1(\phi_{PM})s_B(t)\exp(-\gamma z)\times$$
$$\exp\left\{j\left[(\omega_c+\omega_m)t+\beta(\omega_c+\omega_m)z\right]\right\}, \quad (7)$$

where $\beta(\omega_c+\omega_m)$ is the propagation constant, G is the gain of EDFA, γ is the amplitude attenuation coefficient in optical field, and z is the transmission distance.

When this optical signal is sent to a PD for square-law detection, the output current is

$$I_2(t)=\Re E_{PM\_3}(t)E_{PM\_3}^{*}(t)=$$
$$\Re\alpha^2_{PM}G^2A_c^2J_1^2(\phi_{PM})s_B^2(t)\exp(-2\gamma z), \quad (8)$$

where $\Re$ is the responsivity of PD.

Numerical simulation is performed to verify the feasibility of the photonic envelope detection and fiber transmission scheme. In the simulation, the optical loss of PM is set as α_{PM}=1, and the amplitude of 24 GHz IR-UWB signal is set as A_m=1 mV. The half-wave voltage of PM is $V_{\pi,PM}$=2 V. In Fig.2, the lengths of the EDFA and the fiber are 5 m and 20 km, respectively. The amplitude attenuation coefficient is γ=0.1 dB/km. The bandwidth of FBG in OAEDU is 25 GHz, and the narrow band optical envelope signal is obtained after OAEDU.

Fig.3(a) and (b) represent the signal and spectrum of the 24 GHz band IR-UWB, respectively.

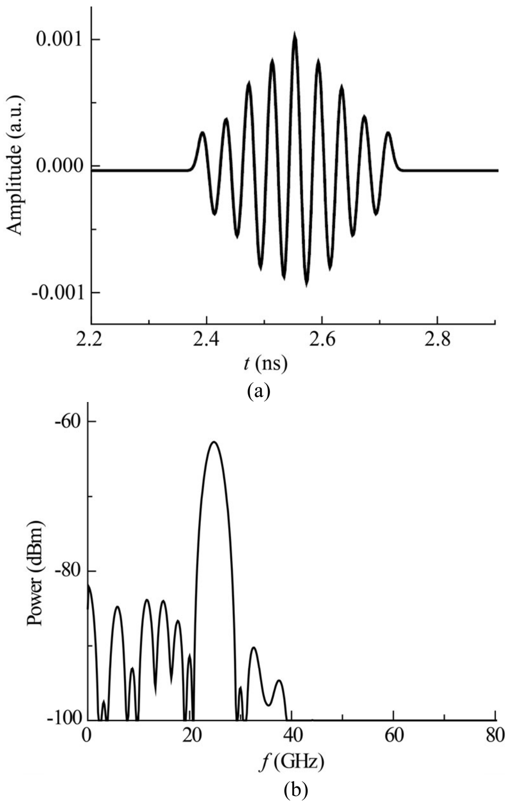
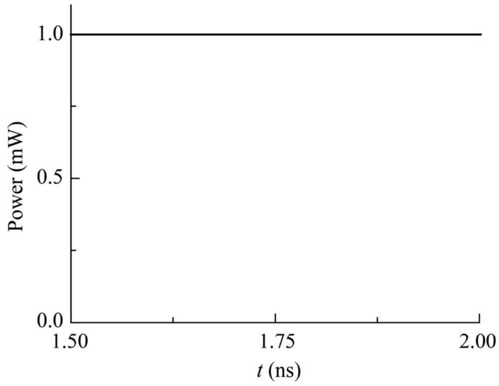


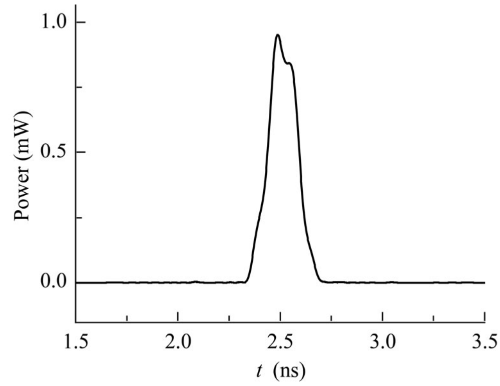
Fig.3 24 GHz IR-UWB: (a) Signal; (b) Spectrum

Fig.4(a) and (c) show the output signal and spectrum of PM. Fig.4(b) and (d) show the output signal and spectrum of OAEDU. It is well known that the system transmission performance is mainly determined by optical spectral width in the propagation. A narrower optical spectral width can make optical signal more tolerant to the CD. In order to obtain the optical signal with narrower spectral width, OAEDU is used for filtering one of the first sidebands at the output of PM. The output signal from OAEDU shown in Fig.4(b) is the narrow band optical envelope signal.

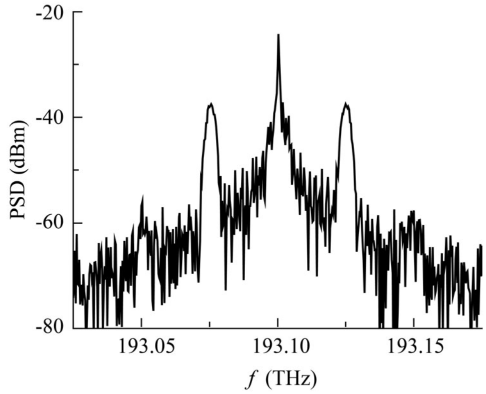
As we can see from Fig.5(a) and (c), the optical envelope signal suffers serious distortion after transmission through SMF. In order to obtain electric envelope signal of IR-UWB, we employ a PD and an LPF to implement the envelope detection. Fig.5(b) shows the electric envelope signal of IR-UWB. As shown in Fig.5(b) and (d), the perfect envelope of IR-UWB can be obtained after transmission over SMF.



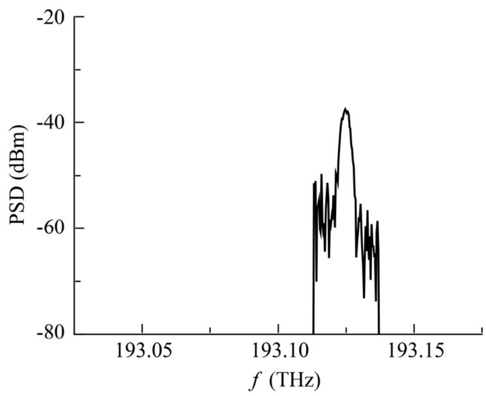
(a) PM output signal



(b) OAEDU output signal

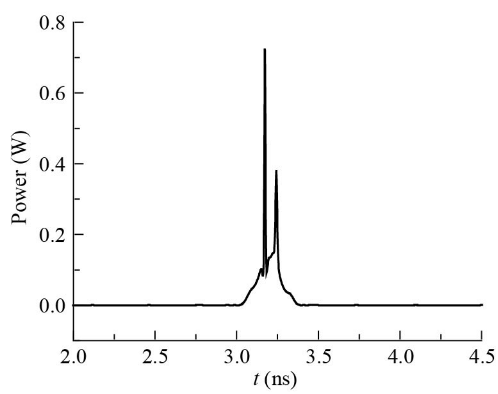


(c) PM output spectrum

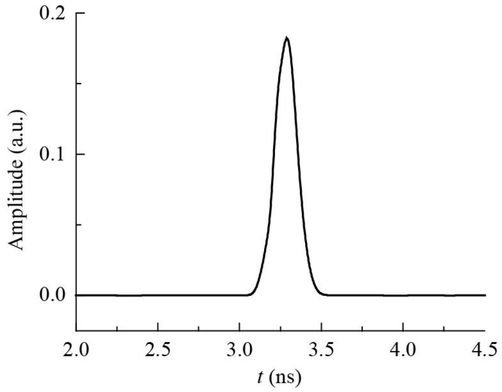


(d) OAEDU output spectrum

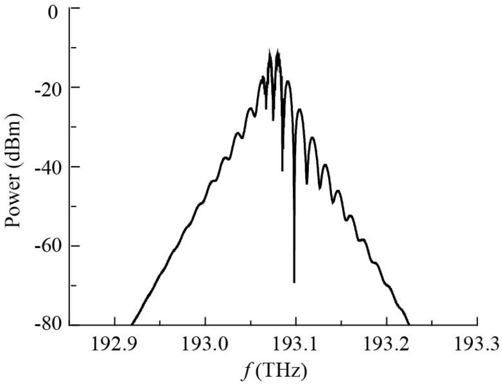
Fig.4 The simulation results for the output signals and spectra of PM and OAEDU using the proposed scheme



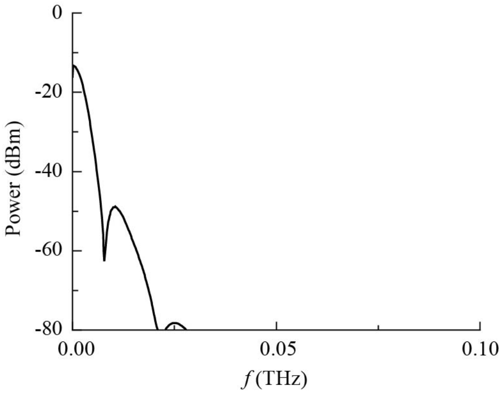
(a) Optical signal after the SMF



(b) Electric envelope signal of 24 GHz IR-UWB after the LPF



(c) Optical spectrum after the SMF



(d) Electric envelope signal spectrum after the LPF

Fig.5 Simulation results for the output signal and spectra of SMF and LPF

In this paper, we demonstrate a novel photonic envelope detection and fiber transmission scheme for 24 GHz IR-UWB signals employing PM. The narrow band optical envelope signal can be obtained by using OAEDU, and it can be more tolerant to the fiber CD than the broadband optical signal. The detailed mathematical derivation and numerical simulation show that the envelope of IR-UWB signal can be obtained effectively. The proposed system can provide a simple and cost-effective solution for IR-UWB receiver.

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