Simulation of mm-wave signal generation using phase modulation in ROF system*

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The generation of optical millimeter waves via the improved phase modulator in a RoF system and the transmission character of the signal are theoretically investigated. A new phase modulating scheme is proposed, in which the sidebands are separated by wave length demultiplexer and one of them doesn't feed digital signals, thereby the phase wake-off is restrained.

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The broadband wireless telecommunication is becoming the main research aspect of the future telecommunication. ROF (radio over fiber) telecommunication technique combines optical fiber with the high frequency radio, thus the broadband wireless communications in 40-60 GHz access can be realized. The generation of millimeter-wave is the key technique of ROF system. Recently, lots of researches have been done in this aspect including direct modulation[1] of the laser, external modulation[2] and optical heterodyne modulation[3-5]. Phase modulation[6] is one kind of external modulation techniques. In such a system, there will be no need of bias voltage, complicated control circuits and the float current brought by the use of bias voltage, therefore, the phase modulation system can provide better robustness and simplified structure than traditional external intensity modulation method. In this paper a new phase modulation scheme is proposed based on the theoretical analysis and simulation.

The principle of phase modulation is shown in Fig.1.

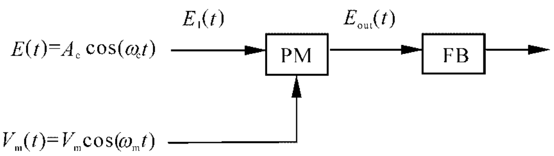

Fig.1 Schemetic diagram of phase modulation

We use the sinusoidal signal without attenuation to describe the signal source and optical light source applied to the modulator. The output wavefront of the phase modulator can be described by formula (1)

$$E_1(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\cos\left[\left(\omega_c + n\omega_m\right)t + n\cdot\frac{\pi}{2}\right] . \quad (1)$$

As shown in formula (1), the power of optical carrier will spread to first-order, second-order, third-order and other higher-order optical sidebands. The amplitude of each sideband is controlled by the parameter β of bessel function. After the even harmonics conversion, the output of the phase modulator is described by formula (2),

$$V_1(t) = C\left[\sum_{n=-\infty}^{\infty} J_n(\beta)\cos[(\omega_c + n\omega_m)t + n\cdot\frac{\pi}{2}]\right]^2 =$$

$$\frac{C}{2}\sum_{n=-\infty}^{\infty}[J_n(\beta)]^2 = \frac{C}{2} , \quad (2)$$

where C is a constant related to A_c and the responsivity of the photodetector.

After the subcarrier suppression by the FBG filter, the output signal of the filter can be described by formula (3),

$$E_{out}(t) = A_c\left\{\sum_{n=-\infty}^{\infty} J_n(\beta)\cos\left[(\omega_c + n\omega_m)t + n\cdot\frac{\pi}{2}\right] - J_0(\beta)\cos(\omega_c t)\right\} . \quad (3)$$

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The output spectrum consists of a series of pulse with different amplitude and phase. The relationship of different pulses is shown in Fig.2, where the $\pi/2$ phase shift between different pulses is not shown in the figure. The slash line represents the optical carrier that has been filtered.

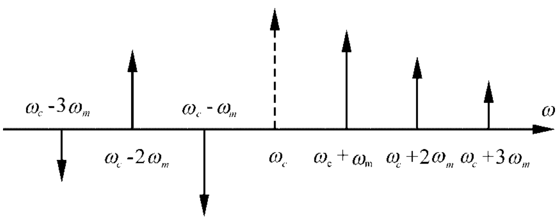


Fig.2 The output spectrum by the FBG filter

The high-frequency signal will be generated as shown in formula (4),

$$V_{\text{out}}(t)=c\{\left[\sum_{n=-\infty}^{\infty}J_n(\beta)\cos(\omega_c+n\omega_m)t+n\cdot\frac{\pi}{2}\right]^2+$$

$$[J_0(\beta)\cos(\omega_c t)]^2-$$

$$2\sum_{n=-\infty}^{\infty}J_n(\beta)\cdot J_0(\beta)\cos\left[(\omega_c+n\omega_m)t+n\cdot\frac{\pi}{2}\right]\cdot\cos(\omega_c t)\}$$

$$=c\{\frac{1}{2}+\frac{1}{2}\cdot[J_0(\beta)]^2-\sum_{n=-\infty}^{\infty}J_n(\beta)\cdot J_0(\beta)\cos[n(\omega_m t+\frac{\pi}{2})]\}$$

$$=c\{\frac{1}{2}-\frac{1}{2}\cdot[J_0(\beta)]^2-2\sum_{n=1}^{\infty}J_{2n}(\beta)\cdot J_0(\beta)\cos[2n(\omega_m t+\frac{\pi}{2})]\}\ . \quad (4)$$

The first two components $C/2$ and $-(C/2)\cdot[J_0(\beta)]^2$ represent the DC component, while the third component $-2C\sum_{n=1}^{\infty}J_{2n}(\beta)\cdot J_0(\beta)\cos[2n(\omega_m t+\pi/2)]$ represents the even harmonics. Peak-to-peak amplitude of each harmonics suffers the attenuation according to the Bessel function. After the suppression of the optical carrier, numerous harmonics[7,8] will be generated. According to formula (4), the phase modulation system can generate the even harmonics while suppressing all the odd harmonics. Also, the efficiency of the suppression and the amplitude will vary according to V_m and f_m. AWG wavelength demultiplexer is used to separate the two sidebands. The baseband signal to be transmitted is modulated to one of the optical subcarrier, thus the eye diagram closure and the restrict of transmission distance caused by the walk-off phenomenon will be diminished.

The simulation link diagram of phase modulation system is shown in Fig.3 according to the diagram of phase modulation shown in Fig.1.

In the system, we define 17 ps/(nm*km) as the dispersion value, which is widely used in real systems. The interference of different D to the system will not be considered in the following parts.

When f_m = 20 GHz, V_m = 0.5, L = 1 km, the simulation result is shown in Fig.4.

The subcarrier is suppressed after the FBG, there are only first-order sidebands, as shown in Fig.4.

During the simulation, fiber with different length is applied to the system to find the change of the simulated eye diagrams. Thus, the maximum of transmission distance can be found. When f_m=20 GHz, V_m=0.5 and D=17 ps/(nm*km), simulation results are shown in Fig.5.

As shown in Fig.5, the eye diagram begins to close when the transmission is about 30 km and close at 50 km. This trend is because of the walk-off caused by chromatic dispersion of the fiber and the time shift of the code edges of the received signal. In order to deal with this question, a novel

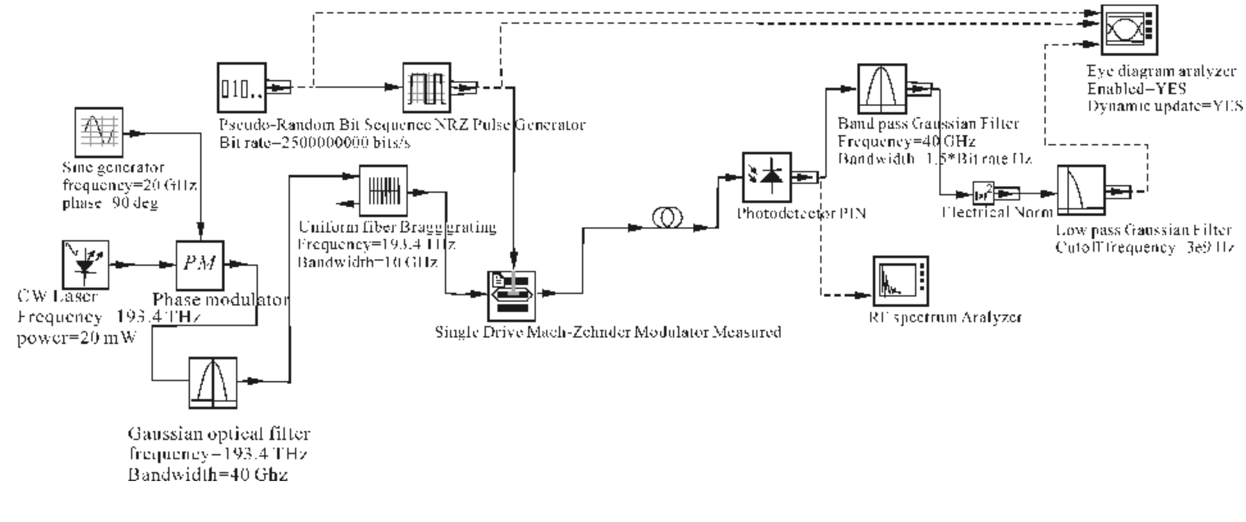


Fig.3 The simulation link diagram of the phase modulation system

phase modulation method is proposed based on the wavelength demultiplexer.

AWG or wavelength demultiplexer is used to separate the two sideband of the modulated optical wave. The

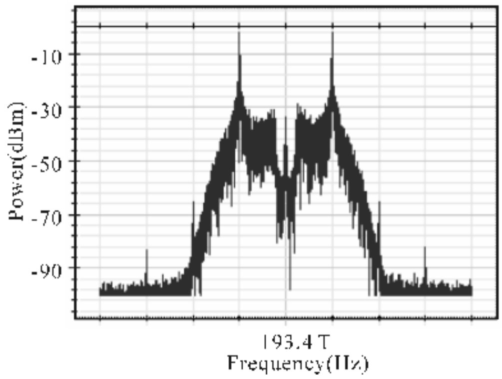
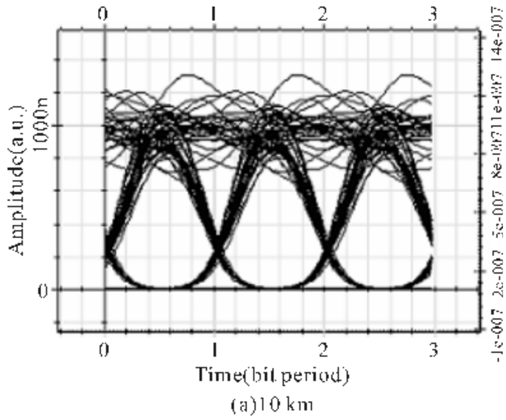


Fig.4 The simulated optical spectrum of phase modulation system



baseband signal to be transmitted is modulated onto one of the optical sideband. So the walk-off phenomenon will be

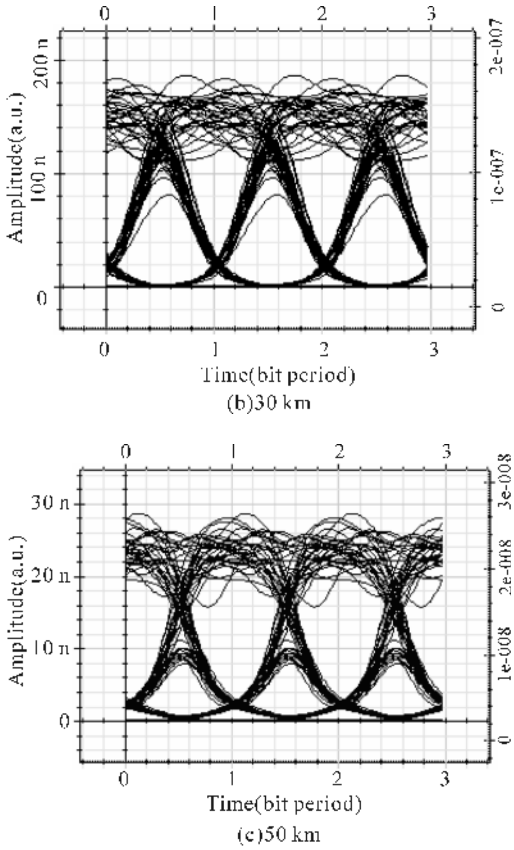


Fig.5 The demodulated eye diagram of phase modulation system

diminished and the transmission distance will be extended.

The refined phase modulation system is shown in Fig.6. The continuous spectrum of laser is sent to optical filter after phase modulation. Subcarrier is suppressed and only two first-order sidebands are left. After that, wavelength demultiplexer made of FBG is used to separate the two sidebands. After the intensity modulation, the baseband signal is modulated the

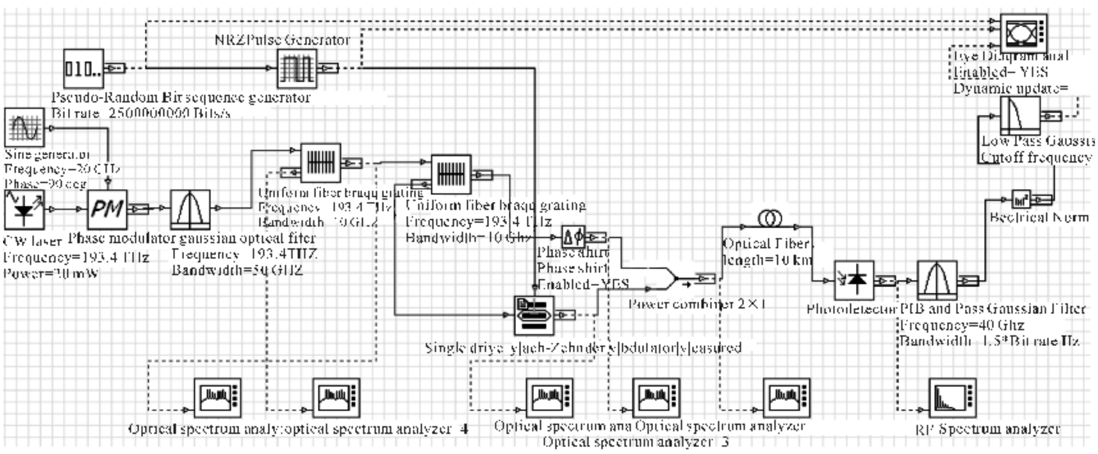


Fig.6 The signal sideband data modulation system

lower sideband while no baseband signal on upper sideband. Thus the walk-off phenomenon caused by chromatic dispersion of fiber is diminished and the transmission distance is extended.

The FGB is used to suppress the upper sideband and the data signal is modulated to lower sideband by MZM. The spectrum is shown in Fig.7.

Different lengths of fibers are used to see the variance of simulation results. When f_m= 20 GHz, V_m= 0.5, D=17 ps/(nm*km), simulation results are shown in Fig.8.

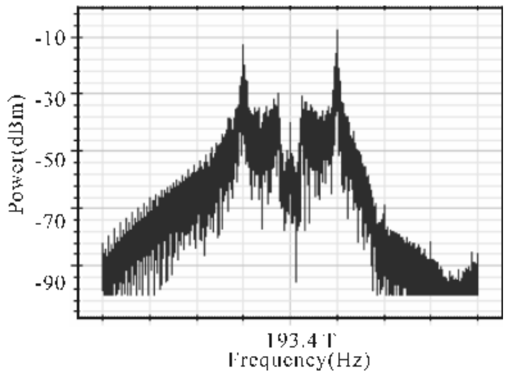
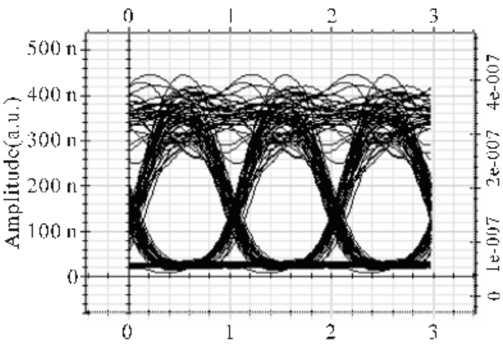
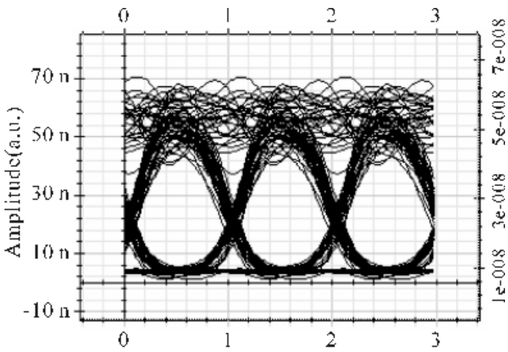


Fig.7 Spectrum after the data signal is modulated to single sideband

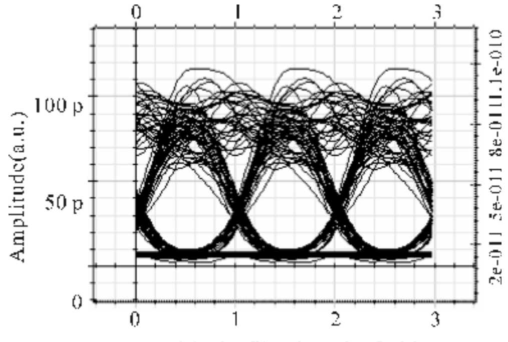
There is almost no interference when the transmission distance is 30 km and the result is almost to 10 km. The performance is better compared with conventional systems. The time shift of the code edges is diminished by the single sideband data modulation. The transmission distance can be infinite in theory. However, the eye diagram tends to close at 220 km. That is probable because of the PMD, nonlinearity and high-order dispersion.



(a) The fiber length of 10 km



(b) The fiber length of 30 km



(c) The fiber length of 50 km

Fig.8 The eye diagram of radio signal according to different length of fibers

In conclusion,the theory analysis of phase modulation system is done in this paper. The efficiency of the suppression of odd-order harmonics and the amplitude of even-order harmonics will vary according to V_m and f_m. The simulation results show that the transmission distance is about 80 km and the eye diagram closes rapidly. That is mainly because of the walk-off phenomenon caused by chromatic dispersion. AWG or wavelength demultiplexer is used to separate the two sidebands. The baseband data signal to be transmitted is modulated to one of the sidebands, thus the walk-off phenomenon is diminished. The transmission distance is extended to 200 km by the new modulation method.

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