Available online at www.ijpe-online.com

International Journal of Performability Engineering

Vol. 13, No. 4, July 2017, pp. 409-417
DOI: 10.23940/ijpe.17.04.p8.409417

Performance Analysis of DPPM Modulation based on Pulsed Fiber Laser

Dongya Xiao[a], Hongzuo Li[a,]*, Huiying Zhang[a,b]

[a]*School of Electronics and Information Engineering Information, Changchun University of Science and Technology, Changchun 130022, Jilin, China*
[b]*School of Information and Control Engineering, Jilin Institute of Chemical Technology, Jilin 132022, China*

Abstract

This paper presents the combination of pulse position modulation (PPM) and pulsed fiber laser in order to improve the problem that the pulsed fiber laser with high power but low repetition frequency results in lower data transmission rate and limits its application. We compare the bandwidth requirement, power requirement, bandwidth utilization and error performance of several schemes of LPPM, DPPM, MPPM and OOK. Also, the modulation rate of three PPM based on fiber laser is obtained. It is shown that DPPM performs best in bandwidth requirement, bandwidth utilization and modulation rate. Moreover, DPPM doesn't require symbol synchronization, which is of great importance in optical communication system. Then the optimal value for DPPM and modulation characteristic of fiber laser are presented. Finally, through simulation and test, we get the results, which shows the feasibility of the scheme.

Keywords: Optical communication; modulation schemes; performance analysis; pulse position modulation; pulsed fiber laser

(Submitted on February 8, 2017; Revised on April 25, 2017; Accepted on June 19, 2017)

1. Introduction

Free space optical (FSO) communication also called wireless optical communication (WOS), which is the product of the combination of optical communication and wireless communication. It is a kind of communication technology which transmits information through laser light in vacuum or atmosphere. FSO owns many obvious advantages like wide bandwidth, low cost, better security, unlicensed spectrum and so on [9]. In the IM/DD modulation schemes, OOK is simple and easy to implement, but its disadvantages of low power efficiency and poor anti-interference ability limit the use in optical communication system. While pulse position modulation (PPM) scheme has higher power efficiency, better anti-interference ability and better error performance, which has been investigated as a method to attain high efficiency in optical communications. With an increase of the communication rate and reliability of laser communication, the traditional semiconductor laser cannot meet the requirements of optical communication. To meet the transmission requirements of high rate and long distance of modern optical communication, the task is to raise modulation rate, transmitting power, conversion efficiency and so on, which leads to the emergence of multitudinous technologies [10].

The pulsed fiber laser is characterized by high power, narrow linewidth, good beam quality but low repetition frequency, which results in lower data transmission rate and limits its application [2]. While the combination of PPM and fiber laser can improve the problem, which makes best use of the advantages of both. Since PPM can achieve higher data transmission rate with lower laser pulse repetition frequency under a given average power of the laser, which can just compensate for the disadvantage of the fiber laser.

* Corresponding author.
E-mail address: lihongzuo@sohu.com.

Based on the existing literature, this paper will present the signal forms for the modulation schemes and analyze the performance including bandwidth requirement, power requirement, bandwidth utilization, error performance of different PPM schemes. Modulation rate based on fiber laser and optimal value for DPPM will be derived. Last simulation and test results will be presented.

2. PPM Signal Forms

As the simplest modulation scheme, OOK uses binary '1' and '0' to represent if there is pulse or not, which is using the on and off light signal to transmit information [3]. PPM employs intermittent periodic pulse as carrier, and the carrier is controlled by the modulation signal, the position of pulse changed to transmit information. In PPM, there are $M=2^n$ slots which convey n bits of information. The anti-interference ability, bandwidth utilization and power efficiency of PPM are much better than that of OOK. PPM includes three modulation schemes which are LPPM (Single-pulse Position Modulation), DPPM (Differential Pulse Position Modulation) and MPPM (Multi-Pulse Position Modulation).

Next, we will analyze the modulation schemes above. The symbol structure of OOK, LPPM, MPPM and DPPM is shown as Figure 1, here the modulation order is n=4.

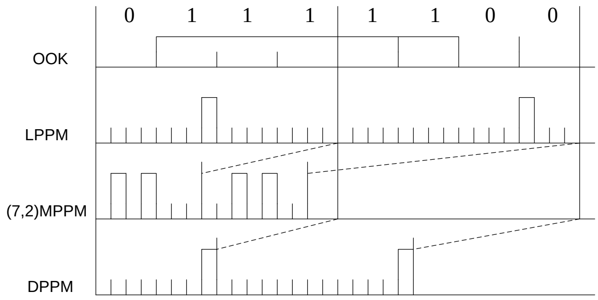

Figure 1: Symbol structure of OOK, PPM, MPPM and DPPM

And the mapping relation of OOK, LPPM, MPPM and DPPM is shown as Table 1, here the modulation order is n=2.

Table 1. Mapping of source bits to transmitted slots for LPPM, DPPM and MPPM

Source bit	OOK	PPM	DPPM	MPPM
00	00	1000	1	1100
01	01	0100	01	1010
10	10	0010	001	1001
11	11	0001	0001	0110

2.1. LPPM

As we known, PPM is an orthogonal modulation technique. In LPPM, every symbol includes L-1 "off" chips, one "on" chip and the number of chips is fixed. Binary n bit data set is mapped into one of L chips, that is to say the optical pulse is transmitted during that chip. The symbol length is T, so each slot length is T/L and the interval duration doesn't overlap in time. The transmitted bit is $\log_2 L(=n)$ each symbol and the pulse shape transmitted is conveyed as [6]

$$s_n(t)=\begin{cases} P & s\tau<t<(s+1)\tau \\ 0 & elsewhere \end{cases} \tag{1}$$

Where s is the position of the pulse, and τ is the time slot width, yields T/L. And a transmitted LPPM signal can be represented as [5].

$$x(t)=LP\sum_{k=0}^{L-1} c_k p\left(t-\frac{kT}{L}\right) \tag{2}$$

Where P is the average power of the pulse signal, $[c_0, c_1 \ldots c_{L-1}]$ is the code word of PPM, and $p(t)$ is a rectangular pulse whose duration is T/L.

2.2. DPPM

DPPM signal is obtained from the corresponding LPPM signal format modified simply. The "0" chips following the "1" chips is deleted if there exists in LPPM, so DPPM signal ends with a pulse. A DPPM signal can be described as the following expression [7].

$$x(t) = \sum_{-\infty}^{+\infty} b_k \cdot P_c \cdot p\left(t - k\frac{T}{L}\right) \tag{3}$$

Where $b_k \in \{0,1\}$, P_c is the peak power of DPPM, $p(t)$ is rectangular pulse with unit- rectangular pulse and duration of T/L. DPPM signal ends with a pulse, which indicates the symbol boundary, so it doesn't need symbol synchronization. It is very important in synchronized optical communication and DPPM scheme can simplify the complication of synchronization design [7].

2.3. MPPM

Generally speaking, MPPM refers to combinatorial PPM, in MPPM, binary n bit data set is mapped into k of M chips, can be noted as (M, k) MPPM. The symbol length is T, so each slot length or duration is T/M. The transmitted MPPM signal can be described as the following expression [4].

$$x(t) = a\sum_{k=0}^{M-1} c_k \phi\left(t - \frac{kT}{M}\right) \tag{4}$$

where $[c_0, c_1 \ldots c_{L-1}]$ is the code word of MPPM, $\phi(t) = \sqrt{M/T} \cdot p(t)$ is rectangular pulse with unit- rectangular pulse and duration of T/M, and where $a = (P/k)\sqrt{MT}$, P is the average optical power. There are $C_M^k = M!/k!(M-k)!$ binary combination number of weight k, while it may be used a part L of these, where $L = 2^n$ and $L \le C_M^k$ [1].

3. Performance Analysis

3.1. Bandwidth requirement

Optical communication needs some bandwidth to transmit information and the smaller, the better. Bandwidth is generally estimated by the main lobe width of the power spectral density that is *sinc* function. As the optical pulse width is narrower, the inverse of the slot width is roughly bandwidth. Here we analyze the bandwidth requirement of modulation schemes above when the bit rate of them is equal. Assuming that the transmission bit is n and time slot width of OOK is τ_{OOK}, so its bandwidth is $B_{OOK}=1/\tau_{OOK}$. We can get the bandwidth of other schemes as follows:

For LPPM, $\tau_{OOK}n=\tau_{LPPM}2^n$, so $B_{LPPM}=B_{OOK}2^n/n$.

For DPPM, $B_{DPPM}= B_{OOK}(1+2^n)/2n$

For MPPM, $B_{MPPM}=B_{OOK}2^n/log_2(L_{MPPM})$

The normalized bandwidth requirement is shown in Figure 2, normalized to B_{OOK} (when k=2 in MPPM).

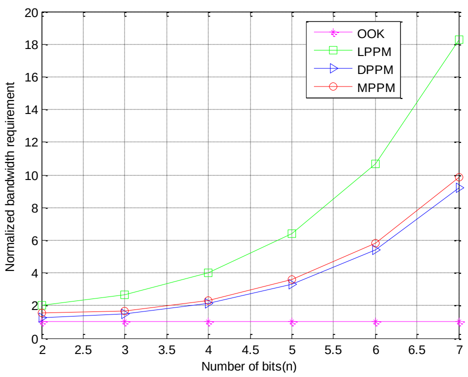

Figure 2. The comparison of normalized bandwidth requirement

The bandwidth requirement of DPPM is minimum, lower than LPPM and MPPM for a given n. The great importance is the symbol synchronization problem as mentioned above [8].

3.2. Average power requirement

Under the condition of same peak power, the average transmitted power of modulation schemes above is analyzed. Here suppose the probability of appearing "0" and "1" is same and the peak power is P_S. Average power is defined as the probability of launching optical pulse "1" multiply by peak power. So the average transmitted power of OOK is $P_{OOK}=0.5P_S$.

For LPPM, $P_{LPPM}=P_S(1/2^n)=2P_{OOK}/2^n$.

For DPPM, $P_{DPPM}=4P_{OOK}/(1+2^n)$.

For MPPM, $P_{MPPM}=2kP_{OOK}/2^n$.

The results are obtained by matlab simulation and the normalized average power curves compared with OOK are shown in Figure 3 (when $k=2$ in MPPM).

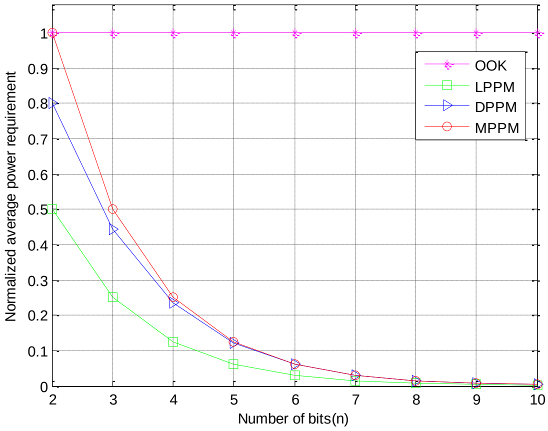

Figure 3. The comparison of normalized average power requirement

It can be seen that the average power requirement of DPPM is lower than MPPM but higher than LPPM for the same peak power and given n.

3.3. Bandwidth utilization

Bandwidth utilization is also called band utilization efficiency, generally defined as,

$$\eta=\frac{R}{B} \tag{5}$$

Where R is data rate, B is bandwidth.

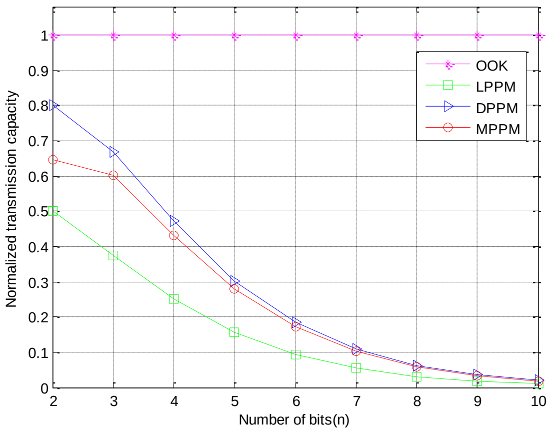

Figure 4. The comparison of band utilization efficiency

The bandwidth B has been given above. Suppose the slot width is τ, then transmission bit is n. For OOK, $\eta_{ook}=(1/\tau)/(1/\tau)=1$. By the same token, we can get the other three schemes.

For LPPM, $\eta_{LPPM}=n/2^n$

For DPPM, η_{DPPM}==$2n/(1+2^n)$
For MPPM, $\eta_{MPPM}=log_2(L_{MPPM})/2^n$ (when $k=2$ in MPPM).
The simulation curves of bandwidth utilization are shown as Figure 4.

It can be seen that for the same time slot width and bit n , the bandwidth utilization of DPPM is higher than MPPM and LPPM.

3.4. Error probability analysis

Error performance is an important performance indicator of optical communication system, which can be measured by the time slot error rate. Using IM/DD scheme for optical communication system, here assuming that only exists the additive Gauss white noise (AWGN), and n(t) is the AWGN with zero mean and variance $\sigma_n^2=N_0/2$. Also the bandwidth of the receiver is considered to be very wide, and the signal $x(t)$ obtained from the input end of the sampling decision can be conveyed as,

$$x(t)=\begin{cases}\sqrt{S_t}+n(t), & \text{when sending "1"}\\ n(t), & \text{when sending "0"}\end{cases} \tag{6}$$

where S_t is the signal peak power of the decision input end. If the decision threshold is b, the probability of "1" mistaken as "0" $P_{0/1}$ and the probability of "0" mistaken as "1" $P_{1/0}$ are given respectively as,

$$P_{0/1}=\frac{1}{2}\left\{1+erf\left[(b-\sqrt{S_t})\Big/\sqrt{2\sigma_n^2}\right]\right\} \tag{7}$$

$$P_{1/0}=\frac{1}{2}\left\{1\text{-}erf\left[b\Big/\sqrt{2\sigma_n^2}\right]\right\} \tag{8}$$

where $erf(x)=2\big/\sqrt{\pi}\int_0^x \exp(-u^2)du=1-erfc(x)$, b is the decision threshold.

So the total error rate is $P_{se}=P_1P_{0/1}+P_0P_{1/0}$. P_1 and P_2 is respectively, the probability of sending "1" and "0", and $P_1+P_2=1$. Suppose the probability of appearing "1" and "0" is the same, so in the OOK modulation, the $P_1=P_0=1/2$. From $\partial P_{se}/\partial b=0$, we can get the optimal decision threshold of OOK is $b=\sqrt{S_t}\big/2$. So,

$$P_{se,OOK}=\frac{1}{2}P_{0/1}+\frac{1}{2}P_{1/0}=\frac{1}{2}erfc\left(\sqrt{S_t/2\sigma_n^2}\right) \tag{9}$$

Similarly, we can get the error probability of other modulation schemes,

$$P_{se}=\frac{1}{2(l+1)}\left[2-erfc\left(\frac{b-\sqrt{S_t}}{\sqrt{2}\sigma_n}\right)+l\cdot erfc\left(\frac{b}{\sqrt{2}\sigma_n}\right)\right] \tag{10}$$

where l indicates that the ratio of the probability of appearing "0" and the probability of appearing "1"in the digital signal sequence and for different modulation schemes, the value of l is different.

Calculating the derivation of the equation (9) to the decision threshold b, and let the guide function is zero, we can get the optimum decision threshold is,

$$b=\frac{2\sigma_n^2\ln(l)+S_t}{2\sqrt{S_t}} \tag{11}$$

Then substitute the expression (10) into (9), we can get,

$$P_{se}=\frac{1}{2(l+1)}\left[2-erfc\left(\frac{2\sigma_n^2\ln(l)-S_t}{2\sqrt{2S_t}\sigma_n}\right)+l\cdot erfc\left(\frac{2\sigma_n^2\ln(l)+S_t}{2\sqrt{2S_t}\sigma_n}\right)\right] \tag{12}$$

For OOK, $l_{OOK}=1$, for LPPM, $l_{\mathrm{LPPM}}=2^M-1$, for DPPM, $l_{DPPM}=\left(2^M-1\right)\big/2$.

And for MPPM, $l_{2MPPM}=(Mm-2)\big/2$, $Mm=\left(1+\sqrt{1+2^{n+3}}\right)\Big/2$.

If signal to noise ratio is defined as $SNR=S_t\big/2\sigma_n^2$. The equation (11) can be written as,

$$P_{se} = \frac{1}{2(l+1)}\left[2 - erfc\left(\frac{2\sigma_n^2 \ln(l) - S_t}{2\sqrt{2S_t}\sigma_n}\right) + l \cdot erfc\left(\frac{2\sigma_n^2 \ln(l) + S_t}{2\sqrt{2S_t}\sigma_n}\right)\right] \tag{13}$$

Under the optimal threshold condition, we have obtained the numerical simulation results between slot error rate and SNR of the different modulation schemes as shown in Figure 5.

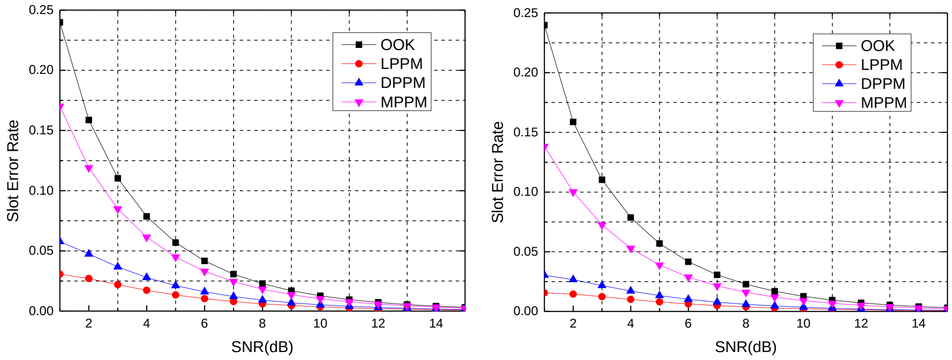

Figure 5. The curve of slot error rate when modulation order n=5 (left) and n=6 (right)

It can be seen from Figure 5, slot error rate decreases with an increase of the signal to noise ratio SNR. When SNR is fixed, the slot error rate of three pulse position modulation schemes decreases with an increase of modulation order n, except OOK modulation. For the same modulation order n, the error performance of LPPM performs the best, DPPM is second only to LPPM and much better than that of MPPM, and OOK is the worst.

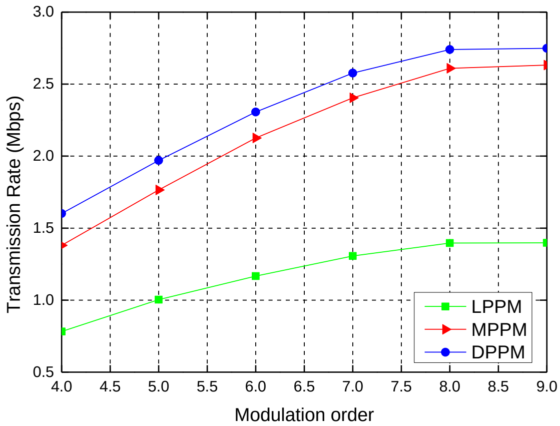

Figure 6. Transmission rate of three modulation schemes

4. Analysis of Modulation Rate

In optical communication system, there is a minimum time interval between adjacent pulses transmitted by pulsed fiber laser, that is the minimum delay time produced by the laser rebuilding a “reverse particle beam”, and we call this period of time guard time slot T_D (Rouissat and Borsali, 2013). A PPM frame period is divided into information segment and protective segment. In the project, the repetition frequency of the pulsed fiber laser used is 200kHz and the pulse width is 3ns, so the guard time slot is T_D=5μs. Suppose the transmission data is random, the time slot width is τ and modulation order is n bit, the frame cycle T of the system can be calculated as $T=L\tau+T_D$ (L is the number of time slot). As the symbol length of DPPM is unstable, the average frame cycle is $T_{DPPM}=(1+2^n)\tau/2+T_D$. The transmission rate is $R=n/T$, by calculating, we get the transmission rate of LPPM, DPPM and MPPM shown as Figure 6.

It can be seen from the curve, DPPM performs the best, and is about twice LPPM. So we have adopted DPPM modulation scheme in our project.

The transmission rate of DPPM is $R=n/T_{DPPM}=n/[5\times10^{-6}+(1+2^n)\tau/2]$. Assuming the pulse duty ratio is 1, that is to say pulse width is equal to time slot width. When n=6,7,8,9,10, and $\tau\in(3ns,15ns)$, the relation curve can be seen as in Figure7.

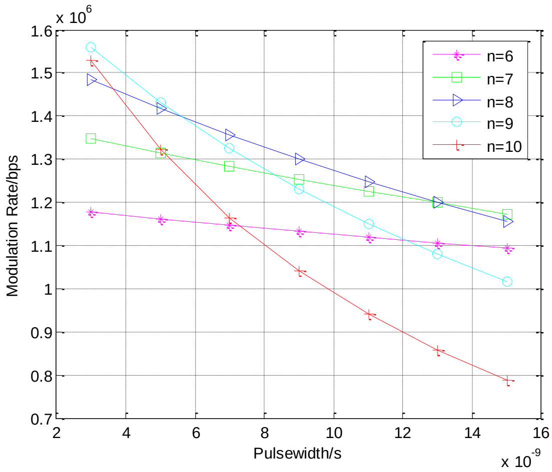

Figure 7. The modulation Rate of DPPM with the change of pulse width and modulation order

5. Modulation Characteristic of Fiber Laser

Modulation characteristic is the relationship between the laser output signal and the modulation signal, here we analyze the relation between the laser output power and the modulation rate of DPPM modulation signal.

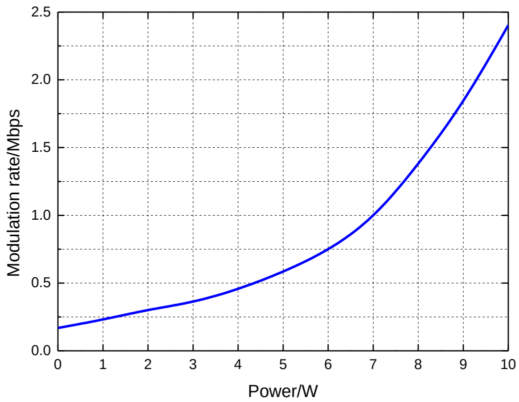

Figure 8. The curve between modulation rate of DPPM and output power

From $P_{out} = P_{\max} \cdot \lambda_0$ and $E_p = P_{\max} \cdot \tau$, we can get,

$$P_{out} = P_{\max} \cdot \lambda_0 = P_{\max} \cdot \frac{\tau}{(L+D)\tau_c} = E_p \cdot \frac{1}{(L+D)\tau_c} \tag{14}$$

Also from the text above, $R = \log_2 L / (L+D)\tau_c$, we obtain,

$$P_{out} = \frac{E_p \cdot R_c}{\log_2 L} \tag{15}$$

When pulse width of the fiber laser τ=3ns, L=256, we get the relation curve between modulation rate and output power shown as Figure 8.

It can be seen from the curve, the output power of pulsed fiber laser doesn't deteriorate because of the effect of DPPM modulation, instead the output power increases with the increase of DPPM modulation rate. So, the combination of fiber laser and DPPM is a good way to improve the system performance.

6. Simulation and Test Results

DPPM modulation system converts the source bit from serial bit sequence into slot pulse sequence and then loads the parallel data on modulator, and the excitation current will changes with the variation of modulation signal. So the output parameters of the laser will change regularly.

First, we simulate DPPM modulation scheme using Modelsim, the input *m* sequence is 1010011, through the serial-parallel conversion, the output is 1010, 0111, 0100, 1110, 1001, 1101, 0011. By comparing with the counter, DPPM signal is obtained. The simulation result is shown as Figure 9.

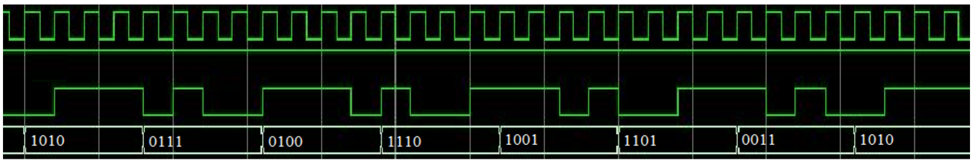

Figure 9. DPPM modulation signal simulation

The block diagram of fiber laser modulation system is designed as Figure 10. The computer transmits binary data to FPFA system board through the serial port, and FPGA converts the input pulse signal into DPPM signal. Then let DPPM signal modulate to fiber laser, and the laser output signal is detected by APD photodetector. Finally, we can see the modulation signal waveform using the oscilloscope as shown in Figure 11 and DPPM modulation rate is about 1.559Mbps.

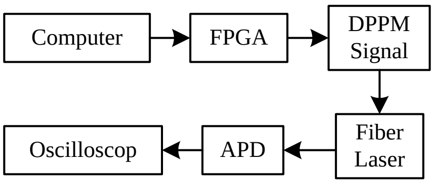

Figure 10. The block diagram of fiber laser modulation system

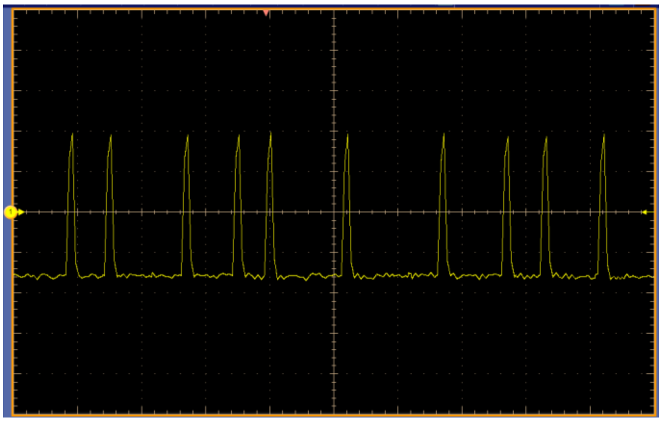

Figure 11. The waveform of DPPM modulation signal

7. Conclusions

In this paper, the combination of pulse position modulation and pulsed fiber laser is presented, which can improve the problem that the pulsed fiber laser with high power but low repetition frequency results in lower data transmission rate and limits its application. We have presented the symbol structure and signal form, compared the characteristics including bandwidth requirement, power requirement, bandwidth utilization and error performance of modulation schemes mentioned above. Then the modulation rate of PPM based on fiber laser is obtained. It is shown that DPPM performs best in bandwidth requirement, bandwidth utilization and modulation rate, moreover DPPM doesn't require symbol synchronization, which is of great importance in optical communication system. Then the optimal value for DPPM and modulation characteristic of fiber laser are presented. At last by simulation and test we get the results, which shows the feasibility of the scheme. The study will be useful for modulation scheme selection and may be applied in designing an optical communication system.

Acknowledgements

This work has been supported by the National Natural Science Foundation of China (Grant no. 60977052).

References

1. Atkin, G. E. and Fung, K.S., "Coded Multipulse Modulation in Optical Communication System", *IEEE Transactions on Communications*, vol. 42, no. 2, pp. 574-582, 1994.
2. Huali Lu, Ming Wang, Xiajuan Dai, Wenhua Guo, "All-Fiber Self-Mixing Interferometer Based on DFB Laser and Phase Modulating Technique", *IEEE Photonics Technology Letters*, vol. 23, no. 4, pp. 221-223, 2001.
3. Mahdiraji, D. M. and Zahedi, Z., "Comparison of selected digital modulation schemes (OOK, PPM and DPIM) for wireless optical communications", in *Proceedings of the 4th Student Conference on Research and Development*, pp. 5-10, 2006.
4. Park, H. and Barry, J.R., "Modulation Analysis for Wireless Infrared Communications", in *Proceedings of the IEEE International Conference on Communications*, pp. 1182-1186, 1995.
5. Rouissat, M., Borsai, A.R. and Chikhbled, M., "Isochronous and Anisochronous Modulation Schemes in Wireless Optical Communication Systems", *International Journal of Information Engineering & Electronic Business*, vol. 4, no. 3, pp. 19-25, 2012.
6. Rouissat, M. and Borsali, R.A., "Differential Two-Pulses Position Modulation for Synchronized Wireless Optical Communications", in *Proceedings of the International Conference on Computer Networks*, pp. 252-257, 2013.
7. Sethakaset, U. and Gulliver, T. A., "Soft-Decision Decoding for Differential Pulse-Position Modulation (DPPM) over Optical Wireless Communications", in *Proceedings of the IEEE Vehicular Technology Conference*, pp. 1-5, 2006.
8. Shiu, D., Kahn, J.M., "Differential pulse-position modulation for Power-Efficient Optical Communication", IEEE Transactions on Communications, vol.47, no. 8, pp.1201-1209, 1999.
9. Viswanath, A., Kar, S. and Jain, V. K., "Analysis of Earth-to-Satellite Free-Space Optical Link Performance in the Presence of Turbulence, Beam-Wander Induced Pointing Error and Weather Conditions for Different Intensity Modulation Schemes", *IET Communications*, vol. 9, no. 18, pp. 2253-2258, 2005.
10. Yan Gao, Min Wu, Weifeng Du, "Performance Research of Modulation for Optical Wireless Communication System", *Journal of Networks*, vol. 6, no. 8, pp. 1099-1105, 2011.