RESEARCH ON M-ARY ARP-VMAP MODEM

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ABSTRACT

In order to improve the spectral efficiency of asymmetry, random-polar and very minimum amplitude and phase (ARP-VMAP) modulated signal, an M-ary ARP-VMAP (MARP-VMAP for short) modulation method is proposed by introduction of the M-ary technology. Firstly, the principle of MARP-VMAP modulation and the two specific modulation methods are demonstrated, namely, MARP-VMAP-I modulation and MARP-VMAP-II modulation, and the modulator model is also given. Then, based on the special filtering mechanism of impacting filter, the demodulator utilizing muti-discrimination is introduced. Finally, The contrast and analysis of the power spectrum, the -60dB bandwidth, the spectral efficiency, and the demodulation performance among ARP-VMAP-I modulation, ARP-VMAP-II modulation, MARP-VMAP-I modulation and MARP-VMAP-II modulation, are carried out. Simulation results show that remaining the same spectrum structure and shape, the new modulation method can multiple the information transfer rate and the spectrum efficiency, and control the loss of demodulation performance about 0.6dB.

Keywords: Asymmetry random-polar and very minimum amplitude and phase modulation, Spectral efficiency, M-ary technology, Impacting filter, Demodulator.

INTRODUCTION

Radio spectrum is an important strategic resource. Whether can fundamentally solve the contradiction between the acute shortage of spectrum resources and the inefficient spectrum utilization has become the goal of many researchers. A class of modulation technique with high spectrum utilization called Ultra Narrow Band (UNB) [1-5] has attracted considerable attention. Walker originally proposed Variable Phase Shifting Keying (VPSK)[1-2], Enhanced Variable Phase Shifting Keying[3], Very Minimum Shift Keying (VMSK)[2] and Pulse Position Phase Reversal Keying(3PRK)[4]. Guoxin Zheng, Lenan Wu etc. put forward Very Minimum Chirp Keying (VMCK)[6],Orthogonal VMCK (OVMCK)[7] ,Extended Binary Phase Shift Keying(EBPSK)[5] ,EBPSK with Continuous Phase (CP-EBPSK)[8], pseudo-random modulated CP-EBPSK[9] and random-polar modulated MCP-EBPSK[10]. These modulations all demonstrate high spectral efficiency. In order to eliminate the transcendental function in the expression of random-polar modulated MCP-EBPSK for the hardware implementation, literature [11] proposed a new modulation that is Asymmetry, Random-Polar and Very Minimum Amplitude and Phase (ARP-VMAP). This modulation can not only remove line spectra in random-polar modulated MCP-EBPSK, but also improve the performance of demodulation. However, ARP-VMAP modulation only carries 1bit information in one symbol period. In view of this, the extension of ARP-VMAP modulation method up to M-ary has important theoretical value and practical significance.

This paper proposes a M-ary ARP-VMAP (MARP-VMAP for short) modulation from the idea of Pulse Position Modulation (PPM) [12-14]. This modulation makes full use of the phase jump position in a single symbol period to carry M-ary information. This makes information transmission rate and spectral efficiency multiplied. Firstly, the principle of MARP-VMAP modulation and the expressions of two specific modulation waveforms are elaborated. And its universal modulator model is given. Then, based on the special filtering mechanism of impacting filter, the demodulator utilizing multi-discrimination is introduced. Finally, the power spectrum and the demodulation performance for the ARP-VMAP modulation and MARP-VMAP modulation are simulated.

MARP-VMAP MODULATION

1. Modulation principle

The waveform expression of the MARP-VMAP modulation in a symbol period $[0, NT_c]$ can be simplified as follows:

$$S_0(t) = A\sin\omega_c t \qquad 0 \le t < NT_c$$

$$S_k(t) = \begin{cases} A\sin\omega_c t & 0 \le t \le (k-1)KT_c \\ B\sin\omega_c t + \xi\cdot D\cdot x(t) & (k-1)KT_c < t < (k-r_g)KT_c \\ A\sin\omega_c t & (k-r_g)KT_c \le t < NT_c \end{cases} \qquad (1)$$

where $k=1,..,M-1$, $S_0(t)$ is the modulated waveform of symbol "0", $S_k(t)$ is of symbol "k", $T_c = 2\pi/\omega_c$ is carrier cycle, $0 \le r_g < 1$ is symbol guard interval control factor, D is amplitude modulation index of additional modulation signal $x(t)$, $\xi \in \{-1, 1\}$ corresponds to current value of a pseudo-random sequence generator for controlling the relative carrier's phase change polarity of additional modulation signal $x(t)$. M、N、K、r_g and D constitute a set of parameters for the change of signal bandwidth, transmission efficiency and demodulation performance. Particularly, when M =2, the MARP-VMAP modulation degenerates into ARP-VMAP modulation. In Formula (1), when the additional modulated signal $x(t) = B\sin(\eta\omega_c t)\cos\omega_c t$, the MARP-VMAP-I modulation can be obtained, whose waveform is shown as below .

$$s_0(t) = A\sin\omega_c t \qquad 0 \le t < NT_c$$

$$s_k(t) = \begin{cases} A\sin\omega_c t & 0 \le t \le (k-1)KT_c \\ B\sin\omega_c t + \xi\cdot D\cdot B\sin(\eta\omega_c t)\cos(\omega_c t) & (k-1)KT_c < t < (k-r_g)KT_c \\ A\sin\omega_c t & (k-r_g)KT_c \le t < NT_c \end{cases} \qquad (2)$$

Where $\eta \in (0,1]$ is power spectrum shape adjustment coefficient. When the additional modulated signal $x(t) = B\cos(\eta\omega_c t)$, the MARP-VMAP-II modulation can be obtained, whose waveform is shown as follows .

$$s_0(t) = A\sin\omega_c t \qquad 0 \le t < NT_c$$

$$s_k(t) = \begin{cases} A\sin\omega_c t & 0 \le t \le (k-1)KT_c \\ B\sin\omega_c t + \xi\cdot D\cdot B\cos(\eta\omega_c t) & (k-1)KT_c < t < (k-r_g)KT_c \\ A\sin\omega_c t & (k-r_g)KT_c \le t < NT_c \end{cases} \qquad (3)$$

2. Modulator model

MARP-VMAP modulator model is given in Figure 1. Among them, the waveform sample storage module stores the modulation waveform samples as shown in Formula (2) or Formula (3). When sending information sequence is symbol "0", we select the waveform sample $S_0(t)$, when sending information sequence is not "0", waveform sample $S_k(t)$ is determined by message sequences and random number generated by a pseudo-random sequence generator. Then, in the control of the clock pulse generated by the clock generator, modulation waveform samples pass through the digital filter and digital to analog converter (DAC) in turn, thereby the MARP-VMAP modulated signal is created.

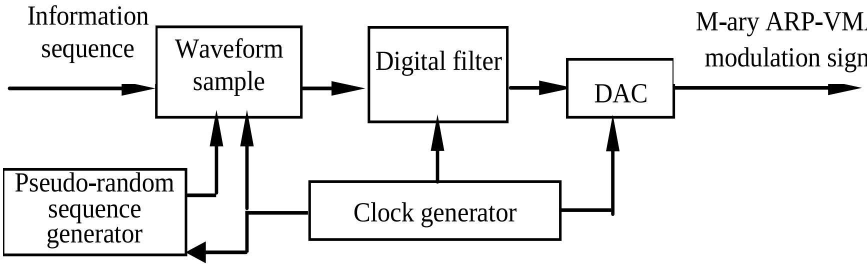
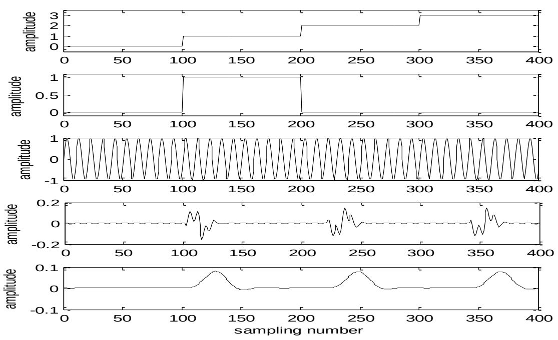


Figure 1 MARP-VMAP modulator model

DEMODULATOR

1. Digital impacting filter

Digital impacting filter [15] is a special kind of infinite impulse response filter. The weak phase jump of the MARP-VMAP modulated signal is converted to the parasitic amplitude modulation in corresponding location by uses of its "notch-frequency selection" characteristics in a very narrow passband. This is conducive to demodulation. If the parasitic amplitude modulation repasses the classic envelope detection (take absolute value and pass a low pass filter), we can eliminate the influence of parasitic amplitude caused by phase's random polarity changes. For example, MARP-VMAP modulated signal with symbols "0","1","2"and"3" passes digital impacting filter (Specific parameters will be given in part 3 of the paper) and envelope detection in turn. As indicated in Figure 2, we can obtain the envelope (From the top to bottom are: information sequence, phase polarity, modulation waveform, impacting output and its envelope). As can be seen, the impact envelope of "0" and non-"0" symbols have difference in amplitude and the impact envelope of different non-"0" symbols are different in position. It has the advantage of using multipath adaptive threshold decision.



Figure(a) MARP-VMAP-I modulation

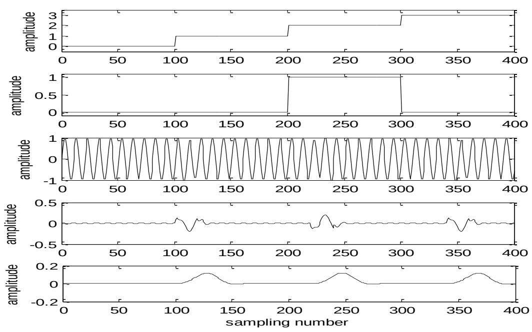


Figure (b) MARP-VMAP-II modulation

Figure 2 impact waveform and envelope

2. Demodulator

Based on the impact filtering mechanism in section 2.1, demodulator model based on digital impacting filter multipath decision is given in Figure 3. Among them, the impact envelope of M-ary information sequence is divided into M-1 paths conducting integral judgment. The first integral decider sets threshold at the envelope impact of symbol “1” to distinguish symbol “0” and “1”. The second sets threshold at the envelope impact of symbol “2” to distinguish symbol “0” and “2” and so forth. Integral decision M-1 sets threshold at the envelope impact of symbol “M-1” to distinguish symbol “0” and “M-1”. Then, the final demodulation result can be obtained by superimposed the verdict of each path via the multiplexer (Note: the envelope impact here is the highest point of the envelope impact at the relative position of a symbol period).

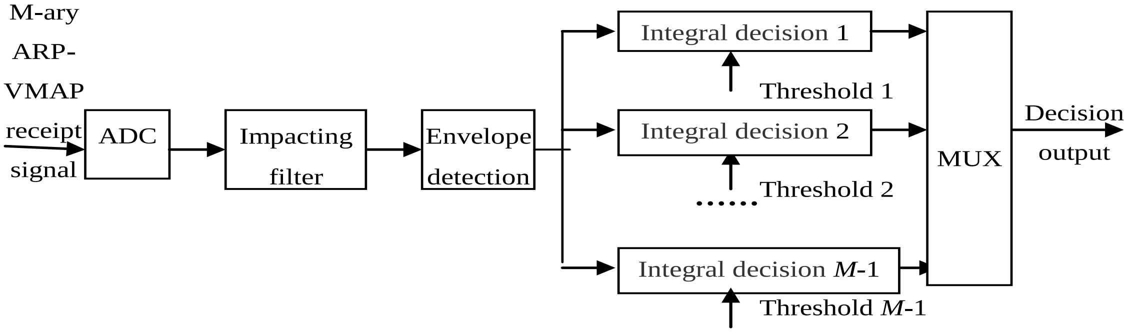


Figure 3 Demodulator model

SIMULATION

Here, the power spectrum and the demodulation performance of ARP-VMAP modulation and 4ARP-VMAP modulation will be simulated. Simulation parameters are set as shown in Table 1. Furthermore, we use digital impacting filter with one pair of conjugate zeros and three pairs of conjugate poles, its transfer function is shown in Formula 4.

Table 1 Simulation parameters

Carrier frequency f_c	21.4MHz
Amplitude A、B	1
Multiple sampling	10
Hexadecimal number M	4
The number of carriers of a single symbol period N	10
The number of carriers of phase jump period K	2
Amplitude modulation index $\triangle$	0.1
Power spectrum shape adjustment coefficient h	1/2
Symbol guard interval control factor r_g	0

$$H(z)=\frac{1+b_1\cdot z^{-1}+b_2\cdot z^{-2}}{1+a_1\cdot z^{-1}+a_2\cdot z^{-2}+a_3\cdot z^{-3}+a_4\cdot z^{-4}+a_5\cdot z^{-5}+a_6\cdot z^{-6}} \quad (4)$$

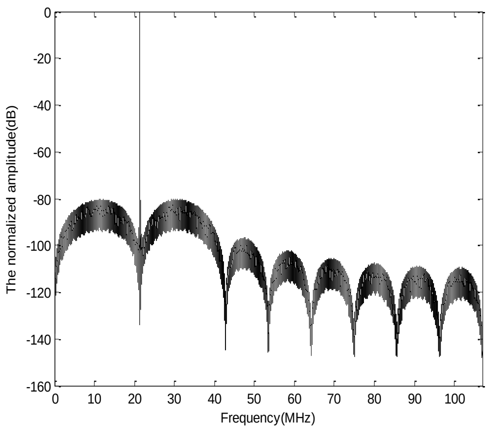
Where, b_1=-1.618495523346314, b_2=1.000000000000000; a_1=-1.973401307621458, a_2=1.707892238042286, a_3=-0.700903759306155, a_4=0.130496898023677, a_5=-0.002568125322230, a_6=0.000019814679492;

1. Power spectrum characteristics

We estimate the power spectra for MARP-VMAP-I, MARP-VMAP-II, 4ARP-VMAP-I and 4ARP-VMAP-II modulations using the Welch spectrum estimation based on Hamming window. According to the strictly -60db sideband level calculated bandwidth and frequency spectrum utilization, the influence of the power spectrum shape adjustment coefficient is analyzed.

(1) Power spectrum

Simulation uses 10^5 symbols and FFT with 2^{26} points in order to ensure the accuracy of spectral estimation. Figure 4 shows the simulation results. We can see that the 4ARP-VMAP modulation can keep the power spectrum structure and shape invariant compared with that of the ARP-VMAP modulation. To further illustrate the influence of multiple technology for the signal bandwidth and spectrum efficiency of ARP-VMAP modulation, its -60db bandwidth and spectrum efficiency are counted up according to the strict -60 bandwidth of the United States Federal Communications Commission (FCC), statistical results are shown in Table 2. It can be seen that compared with the ARP-VMAP modulation, the 4ARP-VMAP modulation can transmit 2bits information in a symbol period at the same time while keeping -60db bandwidth unchanged, so both the bit rate and the spectrum utilization is doubled.



Figure(a) ARP-VMAP-I modulation

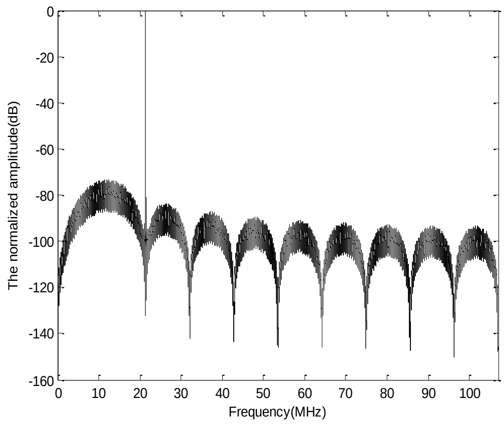


Figure (b) ARP-VMAP-II modulation

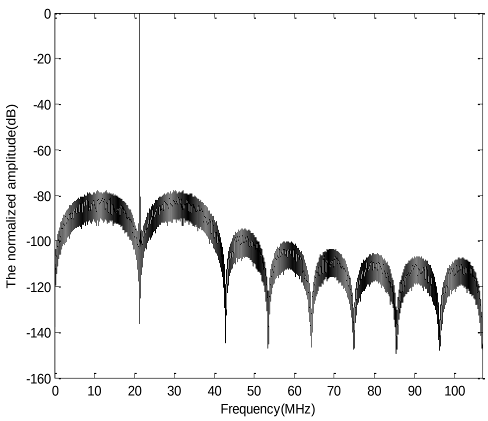


Figure (c) 4ARP-VMAP-I modulation

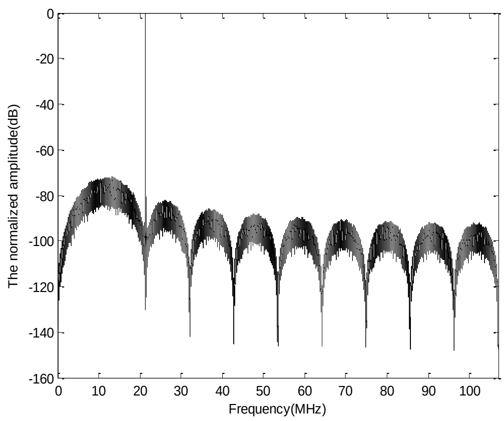


Figure (d) 4ARP-VMAP-II modulation

Figure 4 Power spectrum comparison

Table 2 Comparison of -60dB bandwidth and spectrum utilization among four modulations

Bandwidth(kHz) /Spectrum utilization（bps/Hz）	*N*=10	*N*=20	*N*=30	*N*=40
ARP-VMAP-I	8.97/238	4.48/238	2.99/238	2.22/241
ARP-VMAP-II	8.97/238	4.48/238	2.99/238	2.22/241
4ARP-VMAP-I	8.97/476	4.48/476	2.99/476	2.22/482
4 ARP-VMAP-II	8.97/476	4.48/476	2.99/476	2.22/482

(2) The effect of power spectrum shape adjustment coefficient

To study the power spectrum shape adjustment coefficient's influence on the power spectrum, the power spectrum of 4ARP-VMAP modulation signals are simulated when h is assigned 1/2，1/3 and 1/4 respectively. The results are obtained as shown in Figure 5 and Figure 6. It can be seen that the bandwidth of the power spectrum's main lobe is getting smaller and smaller with the value of h becoming smaller. Signal energy is concentrated to the carrier that is beneficial to improve the energy utilization.

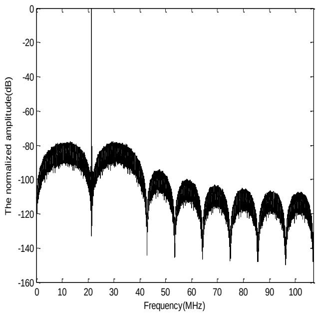


Figure (a) h **=1/2**

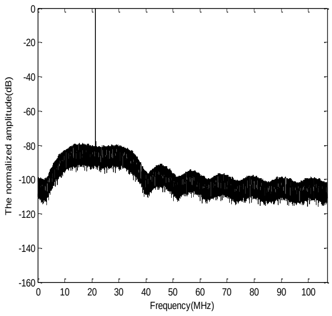


Figure (b) h **=1/3**

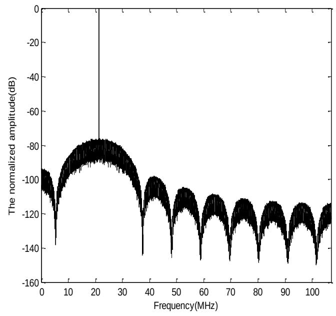


Figure (c) h **=1/4**

Figure 5 Power spectrum of 4ARP-VMAP-I modulation when h **is assigned different value**

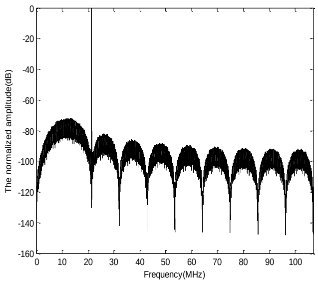


Figure (a) h **=1/2**

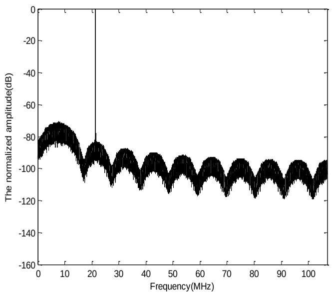


Figure (b) h **=1/3**

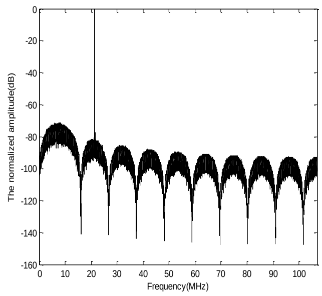


Figure (c) h **=1/4**

Figure 6 Power spectrum of 4ARP-VMAP-II modulation when h **is assigned different value**

2. Demodulation performance

The demodulation performances of ARP-VMAP-I, ARP-VMAP-II, 4ARP-VMAP-I and 4ARP-VMAP-II modulations are simulated with 10^7 symbols at the same time. Bit error rate (BER) curve is got as shown in Figure 7. We can see that the demodulation performance of the 4ARP-VMAP modulation reduces about 0.6dB compared with the ARP-VMAP modulation when BER is at the 10^{-5} magnitude.

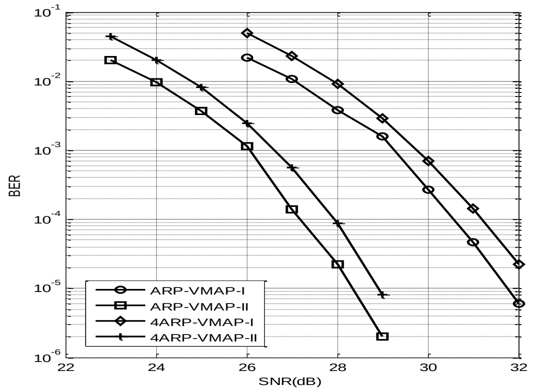


Figure 7 BER of different modulation method

Demodulation performance is simulated when h is assigned 1/2，1/3 and 1/4 respectively. The results are obtained as shown in Figure 8. It follows that: 1) the BER performance is better when h is 1/2 for MARP-VMAP-I modulation; 2) the BER performance is better when h is 1/3 for MARP-VMAP-II modulation.

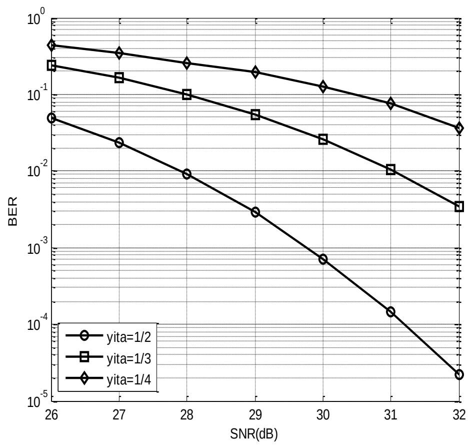


Figure (a) MARP-VMAP-I modulation

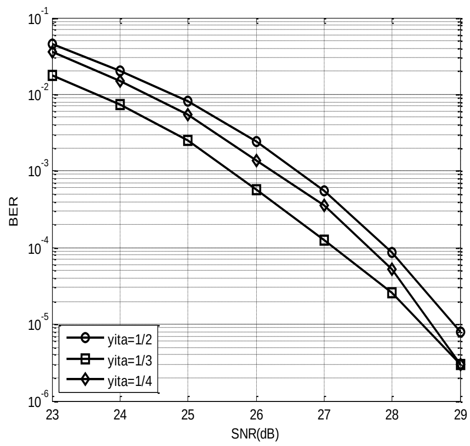


Figure (a) MARP-VMAP-II modulation

Figure 8 BER comparison

CONCLUSIONS

This paper presents MARP-VMAP-I modulation that extends ARP-VMAP modulation to multi-system. The power spectrum and demodulation performance of ARP-VMAP modulation and MARP-VMAP modulation are compared and analyzed. Simulation results show that remaining the same spectrum structure and shape, the new modulation can double the information transfer rate and the spectrum efficiency, and control the loss of demodulation performance about 0.6dB. However, there are still many aspects as follows need to be further studied:

1. Whether there is a better detection method to further improve the demodulation performance.

2. Whether the ARP-VMAP modulation can transmit on cable channel as soon as possible by introducing good channel coding.

3. In this paper, research is limited to the AWGN channel, when the channel is more complex, such as Rayleigh fading channel, shortwave channel and so on, the reliable transmission over these channels remains to be further investigated.

REFERENCES

[1] Walker H R. (1988) *High Speed Binary Data Communication System*. US Patent 4742532.

[2] Walker H R. (1997) VPSK and VMSK Modulation Transmit Digital Audio and Video at 15 Bits/sec./ Hz. *IEEE Transactions on Broadcast Engineering, 43(1)*, 96-103.

[3] Walker H R. (1993) *High Speed Binary Data Communication System using Phase Shift Key Coding*. US Patent 5185765.

[4] Walker H R. (2002) *Digital Modulation Device in a system and Method of using the same*. US Patent 6445737.

[5] Lenan, W. (2007) High-speed communication progress of ultra narrow band. *Progress in Natural Science, 17(10)*, 143-149.

[6] Guoxin, Z., Jinzhen, F., & Minghua, J. (2007, December). Very minimum chirp keying as a novel ultra narrow band communication scheme. *InInformation, Communications & Signal Processing, 2007 6th International Conference on (pp. 1-3). IEEE.*

[7] Guoxin, Z. & Weiying, Y. (2008) The orthogonal very minimum chirp keying (OVMCK) modulations with very high bandwidth efficiency. *IEEE Int. Symp. on Antenna and Propagation and USNC/URSI National Radio Science Meeting, San Diego, USA*, Vol. 1-9, 3182-3185.

[8] Feng, H .& Lenan W. (2009) Analysis of power spectrum of continuous phase waveforms for binary modulation communications. *ICUMT 2009, St. Petersburg, Russia*.

[9] Yu, Z., Pengkui, Y. & Lenan, W. (2012) Pseudo-random modulated CP-EBPSK communication system. *Journal of Southeast University (Natural Science Edition), 42* (2), 209-213.

[10] Yi, J et al. (2012) An MCP-EBPSK Modem with Random-polar. *Journal of Electronics &Information Technology, 34(7)*, 1647-1652.

[11] Lenan, W., Feng, W. & Yu, Z. (2012) *Asymmetry and random-polar very minimum amplitude phase modulator*. The invention patent application number：XXXXXXXX.

[12] Song, S. H., Zhang, Q.T. (2008) CDMA-PPM for UWB Impulse Radio. *IEEE Transactions on Vehicular Technology, 57(2)*, 1011-1020.

[13] Tang, Q et al. (2007) Battery Power Efficiency of PPM and FSK in Wireless Sensor Networks. *IEEE Transactions on Wireless Communications, 6(4)*, 1536-1276.

[14] Song, S. H. &Zhang, Q.T. (2008) TH-CDMA-PPM with Noncoherent Detection for Low Rate WPAN. *IEEE Transactions on Wireless Communications*, *7(2)*, 1536-1276.

[15] Man, F., Peng, G. & Lenan, W. (2010) Analysis and simulation of special filtering based on ultra narrow band modulated signal. *Journal of Southeast University (Natural Science Edition), 40(2)*, 227-230.