NONCOHERENT DEMODULATION WITH VITERBI DECODING FOR PARTIAL RESPONSE CONTINUOUS PHASE MODULATION

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ABSTRACT

With the characteristics of constant envelope and continuous phase, Continuous Phase Modulation (CPM) signal has higher spectrum efficiency and power efficiency than other modulation forms. A noncoherent demodulation with Viterbi decoding for partial response CPM signals is proposed. Simulation results indicate that the demodulation performance of proper partial response CPM is better than the traditional PCM-FM, which is a typical modulation of full response CPM. And higher spectral efficiency is also obtained by partial response CPM.

KEY WORDS

Continuous Phase Modulation, partial response, noncoherent demodulation, Viterbi decoding.

INTRODUCTION

PCM-FM has become the main modulation form in aeronautical telemetry all over the world since the early 1970s. However, PCM-FM signal has the shortage of low spectrum efficiency with large bandwidth occupancy and slow roll-off speed. Due to the increase of spacecraft trials and the telemetry data rate, spectrum bandwidth for aeronautical telemetry has become crowded more and more. Therefore, it is instant to search for new modulation forms with higher bandwidth efficiency and power efficiency. Continuous Phase Modulation (CPM) is proposed to meet the demand. CPM has been adopted into the IRIG-106 telemetry standard.

CPM is a non-linear modulation with memory, since the consecutive symbols are correlative with each other. In general, CPM signals can be represented as[1]

$$s(t,\mathbf{a}) = \sqrt{\frac{2E}{T}} \cos(2\pi f_c t + \phi(t,\mathbf{a}) + \phi_0), \qquad -\infty < t < \infty \tag{1}$$

Where E denotes symbol energy, T denotes symbol duration, f_c denotes carrier frequency, $\phi(t,\mathbf{a})$ denotes the information bearing phase and ϕ_0 is the initial phase.

CPM signal with the characteristic of constant envelope has a certain tolerance against the non-linear distortion caused by non-linear power amplifiers, so as to greatly simplify the design complexity of communication system. Also, the characteristic of continuous phase can reduce the spectrum sidelobe, so as to decrease the channel interference. Even more, Compared with PSK signal, CPM signal itself has a certain coding gain generated by the memory characteristic of its phase-shaping filter, which can be utilized in the demodulation process[2].

PARTIAL RESPONSE CPM

In equation (1), $\phi(t,\mathbf{a})$ can be expressed as:

$$\phi(t,\mathbf{a}) = 2\pi \sum_{i=n-L+1}^{n} a_i h_i q(t - iT) + \pi \sum_{i=-\infty}^{n-L} a_i h_i = \theta(t, a_n) + \theta_n, \qquad nT \le t \le (n+1)T \tag{2}$$

where $\theta(t, a_n)$ denotes the instantaneous phase, which means the changing portion of the phase in the current symbol period; θ_n denotes the cumulative phase before the current symbol; a_i denote information symbols in the M-ary alphabet: $a_i \in \{\pm 1, \pm 3, ..., \pm M - 1\}$; h_i are modulation indices, with kinds of single-h mode and multi-h mode; L is a positive integer, when $L = 1$,it denotes full response CPM; when $L \ge 2$, it denotes partial response CPM; $q(t)$ is the phase function, which can be expressed as the integral of a certain frequency pulse $g(t)$:

$$q(t) = \int_0^t g(\tau) d\tau \tag{3}$$

Two commonly used frequency pulse shapes $g(t)$ are listed in Table 1.

Table 1 CPM frequency pulse shapes

LREC	$g(t)=\begin{cases}\frac{1}{2LT}, 0\le t\le LT\\ 0, otherwise\end{cases}$
LRC	$g(t)=\begin{cases}\frac{1}{2LT}[1-\cos(\frac{2\pi t}{LT})], 0\le t\le LT\\ 0, otherwise\end{cases}$

In equation (2), θ_n can be expressed in the formulation $\theta_n=\frac{2q\pi}{p}\sum_{i=-\infty}^{n-L}a_i=Q\frac{2\pi}{p}$, where $h=2q/p$, p and q are coprime integers, $Q=q\sum_{i=-\infty}^{n-L}a_i$ is an integer. Then the state number of θ_n can be denoted as $\frac{2\pi}{(2\pi/p)}=p$. Then, in a symbol duration $t=nT$, the states of CPM signal can be defined as $s_n=(\theta_n,a_{n-1},a_{n-2},...,a_{n-L+1})$. So the total number of states is $S=p\times M^{L-1}$.

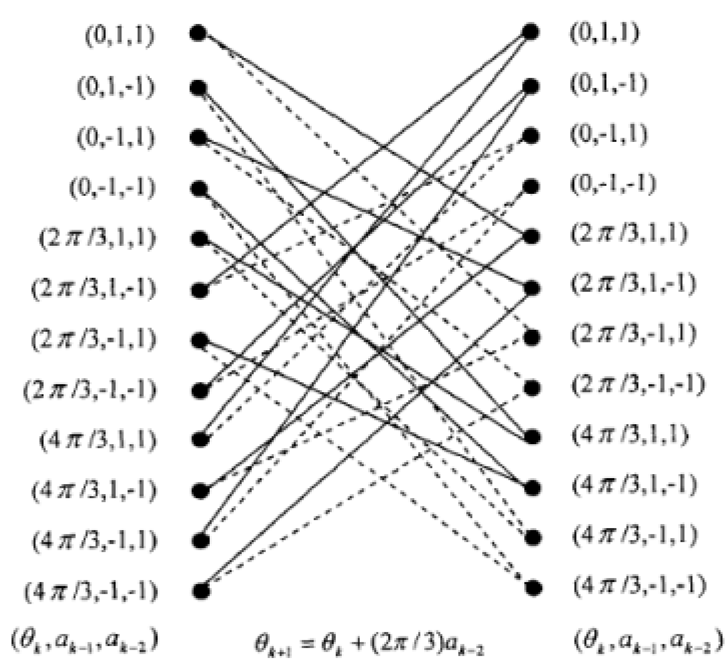


Figure 1. CPM trellis diagram ($g(t)=3RC$, $h=2/3$ and $M=2$)

In equation (2), θ_n also can be expressed in a recursive form: $\theta_{n+1} = \theta_n + h\pi a_{n-L+1}$. Then we can use a trellis diagram to describe the states of CPM signal. For example, Figure 1 shows a CPM signal trellis diagram in the condition of $g(t) = 3RC$, $h = 2/3$ and $M = 2$, where the solid line indicates symbol " +1 " and the dotted line indicates symbol " -1 ".

By selecting different frequency pulse shapes $g(t)$, changing the modulation indices h_i and modulation number M, we can generate infinite CPM signals. The paper focuses on the binary single-h partial response CPM signals.

VITERBI DETECTION ALGORITHM

Because the CPM signal can be represented in a finite state trellis, the Viterbi algorithm can be used for recovering the modulated data. The Viterbi algorithm can be summarized as follows[3]:

1. calculating each branch metric: calculating the branch metric into the node of S branches at $(n+1)T$ duration;
2. updating each path metric: updating the path metric with the branch metric obtained in step 1 on the basis of the survivor path from previous duration nT. Then, at $(n+1)T$ duration, each node will have S numbers of path metric;
3. determining survivor path: by comparing N numbers of updated path metrics for each node at $(n+1)T$ duration, retaining the path whose path metric is maximum and discarding the remaining $N-1$ paths. After the above operation for all state modes, each mode will only survive one path. Reserve the survivor path data and its path metric.
4. obtaining demodulation data: repeating the 1-3 steps in every symbol duration until the end of the sequence. Then, choosing the path with the maximum path metric as the maximum likelihood path. At last, tracing the saved data path, and obtaining demodulation data.

SIMULATION RESULTS AND ANALYSIS

Based on the above analysis and research of the partial response CPM signal and its demodulation algorithm, we simulate the CPM system on the MATLAB platform. The simulation block diagram is shown in Figure 2, where the channel model is AWGN.

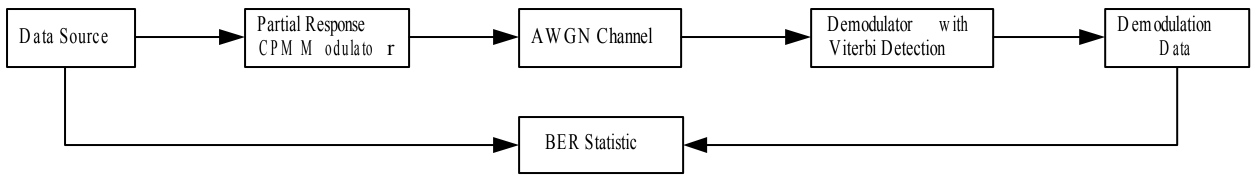
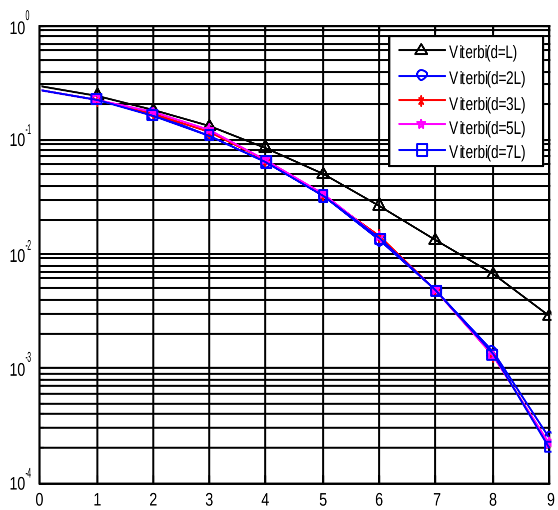


Figure 2. Block diagram of simulation

(1) the effect of decision delay d

The BER (bit error rate) performance of partial response CPM signal with different decision delay d is shown in Figure 3, where $g(t)=2RC$, $N_R=2$, $M=2$ and $h=2/3$. It is seen that the performance is greatly improved when decision delay d changes from L to $7L$. Meanwhile, the delay time of demodulation data and memory for storage of survivor path increases linearly. So in the premise of ensuring demodulation performance, we should choose d as small as possible, generally $d=5L$.



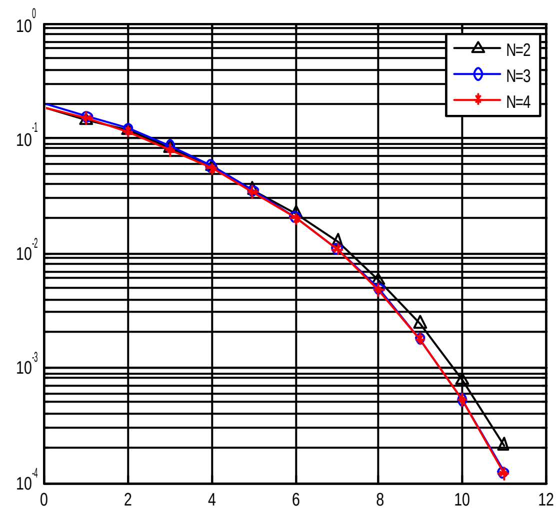


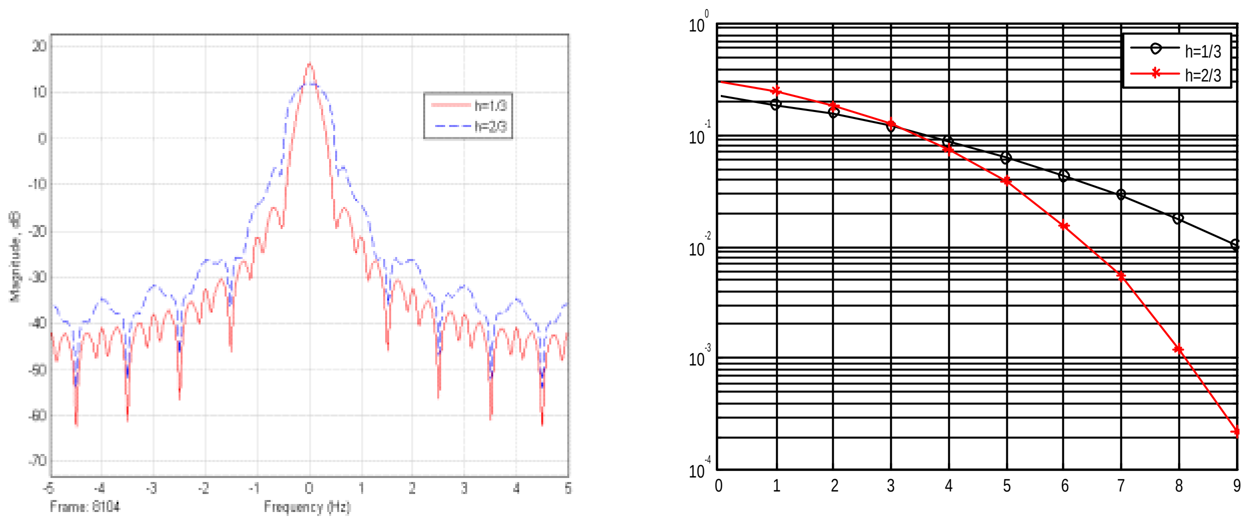
Figure 3. BER with different decision delay d Figure 4. BER with different decision depth N_R

(2) the effect of decision depth N_R

Figure 4 shows BER performance of partial response CPM signal with different decision depth N_R, where $g(t)=2RC$, $d=5L$, $M=2$ and $h=1/3$. It is seen that the performance is improved when decision depth N_R varieties from 2 to 4, while the performance has reached its limitation when N_R is 3. It should be pointed out that, the demodulation complexity increases exponentially with N_R. So it is essential to take both the performance and the complexity into consideration. In general, for single-mode partial response CPM, we can choose $N_R = L$ or $N_R = L+1$.

（3） the effect of modulation index h

Figure 5 shows the BER performance of partial response CPM signals with different modulation index h, where $g(t)=2REC$, $M=2$, $d=5L$ and $N_R=2$. As shown in the curves, with the increasing of the modulation index h from 1/3 to 2/3, the spectrum bandwidth of CPM signals broadens, while the demodulation performance improves. So it need search proper modulation index h to balance spectrum efficiency and power efficiency.

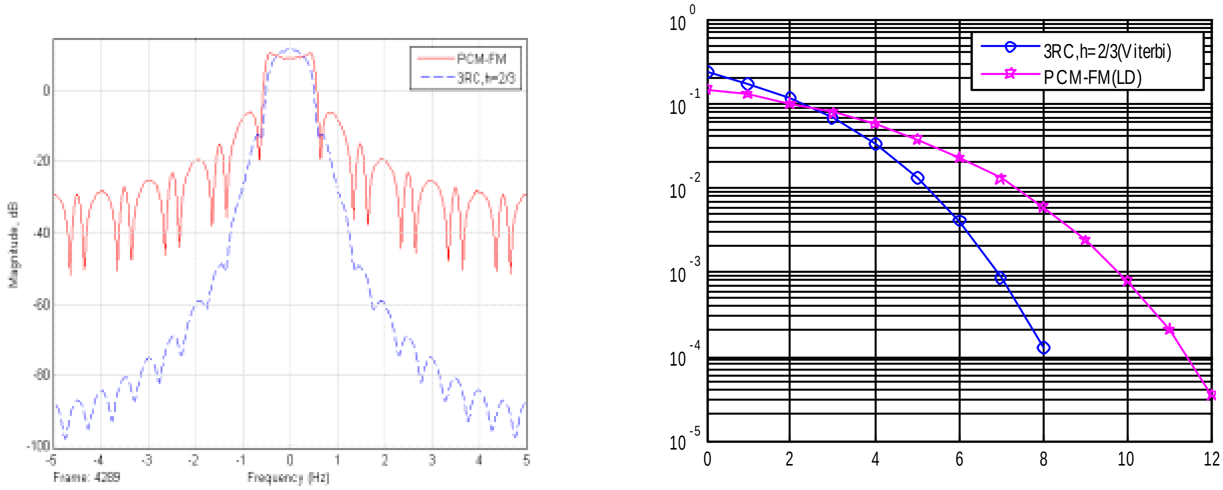


(a) spectrum characteristic (b) demodulation performance

Figure 5. Performance with different modulation index h

（4） comparison of full response CPM and partial response CPM

The comparison of spectrum characteristic and demodulation performance between full response CPM and partial response CPM is presented in Figure 6. The parameters of partial response CPM are $g(t)=3RC$, $M=2$, $d=5L$, $N_R=4$, $h=2/3$; while full response CPM chooses the traditional PCM-FM signal with $g(t)=1REC$, $M=2$, $h=7/10$. Simulation results show that partial response CPM occupies less bandwidth with faster spectrum roll-off, so the spectrum efficiency can be improved greatly. At the same time, the partial response version has a better demodulation performance than PCM-FM with non-coherent limited discrimination demodulation. It implies that, by choosing proper modulation characteristics and demodulation algorithm, partial response CPM can achieve better performance in both spectrum efficiency and power efficiency than full response CPM.



(a) spectrum characteristic (b) demodulation performance

Figure 6. Comparison of partial response CPM and full response CPM

CONCLUSIONS

The paper firstly introduces the basic concept and characteristics of CPM signal. CPM has good spectrum efficiency and power efficiency, which can efficiently relieve the pressure of bandwidth constraint in the current aeronautical telemetry. Then, a demodulation scheme based on the Viterbi detection algorithm for partial response CPM is proposed and simulated by MATLAB. The effect of certain parameters such as decision delay, decision depth and modulation index on spectrum characteristic and demodulation performance is analysed. Finally, we compare partial response CPM with full response CPM. It indicates that, by choosing proper modulation characteristics and demodulation algorithm, partial response CPM can achieve better performance in both spectrum efficiency and power efficiency than full response CPM.

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