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Analysis and Research of 2DPSK Signal Reception Based on Stochastic Resonance System under Levy Noise

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Abstract

Under the background of Levy noise, a new method for coherent demodulation of 2DPSK signal based on the bistable stochastic resonance system model is proposed to solve the problem of poor quality of 2DPSK signal coherent demodulation. Comparing the output signals of the bistable stochastic resonance system model and the traditional model after passing through various components, the analysis shows that the frequency spectrum amplitude of the carrier signal after passing through the bistable stochastic resonance system model is approximately higher than that of the traditional model. 1.26 times. The error code of the output signal after demodulation by the new method is less than that of the traditional model after demodulation, and the signal to noise ratio is improved by 12.5dB. The simulation experiment results prove that the bistable stochastic resonance nonlinear coherent demodulation method effectively improves the transmission quality of 2DPSK signals.

Keywords: levy noise; 2DPSK signal; cascaded stochastic resonance system; coherent demodulation.

1. Introduction

In 1981, Benzi[1-2]proposed the concept of stochastic resonance when studying the problem of the earth's climate affected by glaciers. Stochastic resonance refers to a kind of nonlinear dynamic phenomenon produced by resonating the three of weak signal, noise and nonlinear system[3-5]. At present, there are two methods for detecting weak signals using stochastic resonance theory in the background of strong noise. One is to manually adjust the noise parameters, and the artificial interference noise resonates with the system.

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The other is to use a nonlinear system to optimize the parameter adjustment to make the system. The noise enters a stable "resonance" state, at which time the noise energy is suppressed and the signal energy is strengthened. Both methods can finally extract weak signals, but the process is different. Binary differential phase shift keying is also called binary relative phase shift keying(2DPSK)[6]. It uses the difference between the relative carrier phases of two adjacent symbols before and after to transmit digital information. The 2DPSK signal has good anti-noise performance and overcomes the shortcomings that the local carrier recovered by the 2PSK signal may be reversed from the required coherent carrier, and is more widely used in real life. In this paper, the Levy noise, which has strong impact, universality, and the influence of random factors generated by multiple random variables, is used for simulation experiments. As a result, compared to the ideal Gaussian white noise, it can better represent the impact characteristics in the channel environment, making the research scope of stochastic resonance wider and closer to real life. In the Levy noise environment, the 2DPSK signal is combined with the bistable stochastic resonance system, and the output signal is studied and analyzed. The structure of the bistable stochastic resonance system is simple and stable, which is conducive to the extraction of low-frequency signals. At present, most of the applications of stochastic resonance in the detection and processing of analog signals, there are few studies on the application of stochastic resonance theory in the detection and processing of digital signals. This paper uses the principle of bistable stochastic resonance to add the influence of Levy noise to propose a new method of demodulation and detection of 2DPSK signals. The signal is input into the band-pass filter, multiplier and low-pass filter and other components and compared with the traditional 2DPSK coherent demodulation method. Then discover the advantages of bistable stochastic resonance system in binary differential phase shift keying digital signal processing.

2. Levy Noise Distribution

Levy noise is a concept proposed by the Finnish mathematician Lindburg-Levy[9]. The propagation form of Levy noise has the characteristics of non-Gaussian distribution and is closer to the actual environment. Levy noise distribution is affected by four parameters α, β, σ, and μ. The four parameters determine the stability, symmetry, dispersion, and center position of the noise distribution. The expressions of the dependent variable are described as follows:

$$\log(t)=\begin{cases}-\sigma^{\alpha}|t|^{\alpha}\{1-i\beta sign(t)\tan(\frac{\pi\alpha}{2})\}+i\mu t, & \alpha\neq 1,\\ -\sigma|t|\{1+i\beta sign(t)\frac{2}{\pi}\log|t|\}+i\mu t, & \alpha=1,\end{cases} \tag{1}$$

In formula (1), $\alpha\in(0,2],\beta\in[-1,1],\sigma\in[0,\infty),\mu\in(-\infty,+\infty)$. α is the characteristic index, which affects the pulse characteristics of the noise distribution. If α is 1 and 2, the noise distribution satisfies the Cauchy distribution and the Gaussian distribution respectively. β is the skew parameter, which controls the left and right tilt of the distribution. σ is the dispersion coefficient, and the dispersion degree of the distribution with respect to μ is affected by the dispersion coefficient. μ is a position parameter, and the left and right movement of the graph is controlled by μ. Rafal Weron et al. used uniformly distributed variables and exponentially distributed variables to solve and prove the equation in 1995. The expression of random variables is as follows:

$$X = S_{\alpha,\beta}\frac{\sin(\alpha(V+B_{\alpha,\beta}))}{}\left(\frac{\cos(V-\alpha(V+B_{\alpha,\beta}))}{W}\right)^{(1-\alpha)\alpha},\ \alpha \neq 1, \quad (2)$$

$$X = \frac{2}{\pi}[(\frac{\pi}{2}+\beta V)\tan(V)-\beta\log(\frac{W\cos(V)}{\frac{\pi}{2}+\beta V})], \alpha = 1, \quad (3)$$

In formulas (2) and (3), V is a uniform distribution on the $(-\pi/2, \pi/2)$ interval, W is an exponential distribution with a mean value of 1. $S_{\alpha,\beta}$ and $B_{\alpha,\beta}$ the definition expression[9] is as follows:

$$S_{\alpha,\beta} = [1+\beta^2\tan^2(\frac{\pi\alpha}{2})]^{1/(2\alpha)}. \quad (4)$$

$$B_{\alpha,\beta} = \frac{\arctan(\beta\tan(\frac{2\pi}{2}))}{\alpha}. \quad (5)$$

3. 2DPSK Signal Modulation and Demodulation Principle

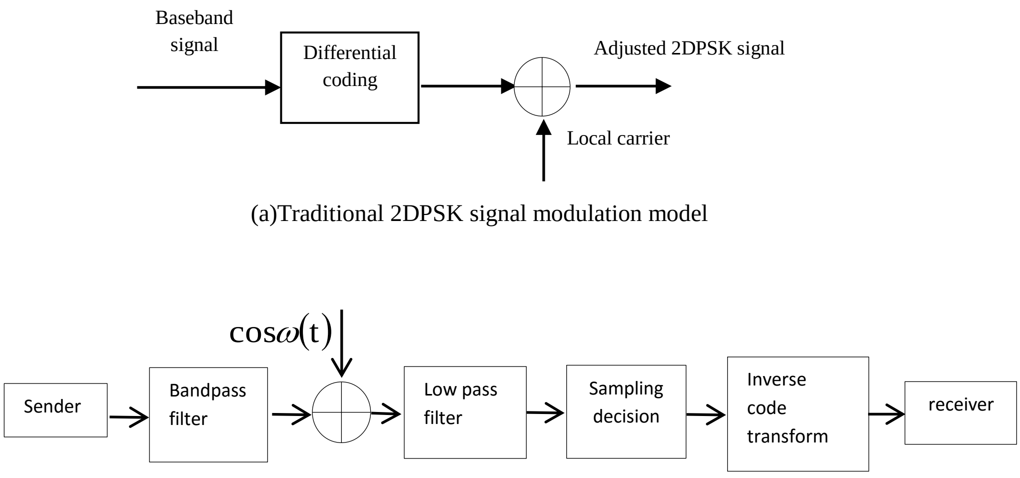
The well-known 2PSK signal takes the carrier phase as "0" to represent the "1" in the binary symbol, and takes the carrier phase as "π" to represent the "0" in the binary symbol. In order to overcome the shortcoming that the local carrier of the 2PSK signal may be inverted from the required coherent carrier, a binary differential phase shift keying (2DPSK) method is proposed. The 2DPSK signal uses the difference of the relative carrier phases of two adjacent symbols before and after to transmit digital information.Take $\Delta\varphi$ to represent the difference between the initial phase of the current symbol and the initial phase of the previous symbol, which is referred to as the phase offset value for short.When $\Delta\varphi$ is 0, the digital information is "0". When $\Delta\varphi$ is π, the digital information is "1". The modulation method of 2DPSK is to first perform differential encoding on the binary digital baseband signal[7-8]. If the absolute code of the digital information sequence is set to $a(t)$, the expression of the modulated 2DPSK signal in any symbol time is

$$s(t) = A\sin[\omega ct + a(t)], a(t) = 1 or 0 \quad (6)$$

The absolute code $a(t)$ is differentially encoded to obtain the relative code $b(t)$, the differential encoding is $b(t) = a(t) \oplus b(t-T)$, and the differential decoding is $a(t) = b(t) \oplus b(t-T)$, and the relative code $b(t)$ is subjected to the 2PSK modulation method to obtain the modulated 2DPSK signal and obtain any of its codes The expression in the meta time T is

$$s(t) = A\sin[\omega ct + b(t)\pi], b(t) = 1 or 0 \quad (7)$$

The model of 2DPSK signal modulation and demodulation is shown in Figure 1.



(b)Coherent demodulation model of traditional 2DPSK signal

Figure 1: Basic modulation and demodulation model

4. Stochastic Resonance Signal System Model

In the Levy noise environment, the 2DPSK signal is combined with the bistable stochastic resonance system and the output signal is analyzed and studied. The output of the stochastic resonance system satisfies the Langevin[10-12] equation as:

$$\frac{dx}{dt} = ax(t) - bx^3(t) + s(t) + n(t) \quad (7)$$

Where $x(t)$ is the output signal of the bistable system $U(x)$, where a and b are the two system parameters of the bistable system $a, b > 0$, $s(t)$ is the input modulated 2DPSK signal, and $n(t)$ Z is the Levy noise with intensity D. The classical bistable stochastic resonance system and potential function are expressed as

$$dx/dt = ax - bx^3 (a > 0, b > 0) \quad (8)$$

$$U(x) = -ax^2/2 + bx^4/4 \quad (9)$$

Figure 2 is the principle diagram of coherent demodulation of the modulated and noise-added 2DPSK signal after passing through the bistable stochastic resonance system. After the modulated signal bistable stochastic resonance system, it is consistent with the traditional signal demodulation model, and finally the output result is obtained.

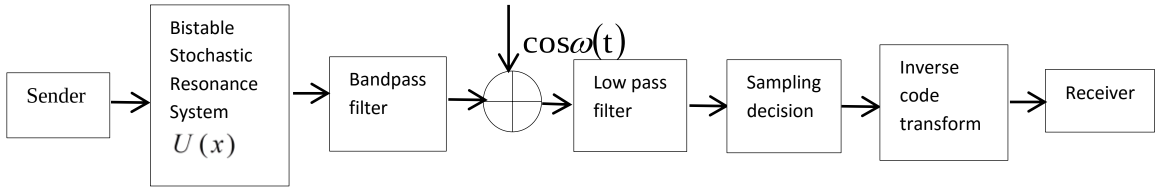
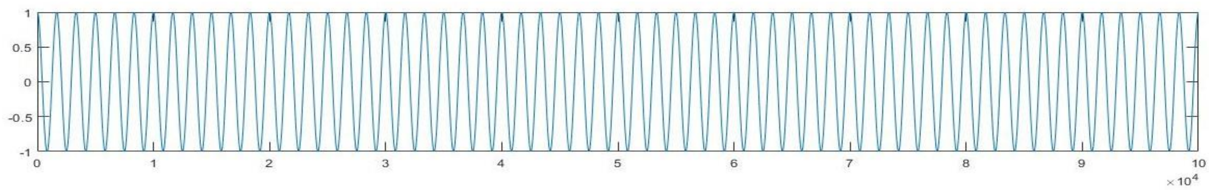


Figure 2: Demodulation model after cascaded stochastic resonance nonlinear system

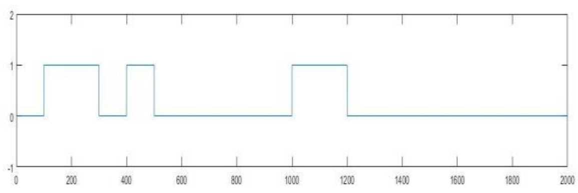
5. Numerical Test and Performance Analysis of System Output

5.1 Signal Modulation and Noise

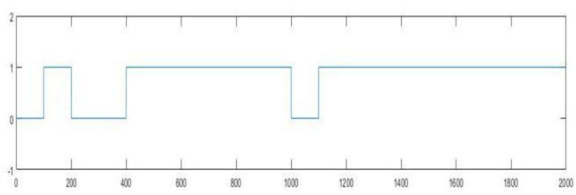
First, modulate the 2DPSK signal to obtain the time-domain waveform [13] and frequency spectrum of the initial 2DPSK signal, and analyze the modulation results. The transmitted digital symbols are differentially coded, the relative code $b(t)$ can be obtained from the absolute code $a(t)$, and the generated relative code $b(t)$ and its inverse code are multiplied with the local carrier to modulate the signal according to the modulation principle shown in Figure 1(a). Tuned 2DPSK signal. Figure 3(a) is the signal diagram of the local carrier, Figure 3(b) is the absolute code, Figure 3(c) is the relative code, and Figure 3(d) is the relative code and the opposite of the relative code respectively from Figure 3(e). Signal diagram after multiplying code and carrier. Figure 3(d) is combined with Figure 3(e) to get Figure 3(f) is the time-domain waveform of the modulated 2DPSK signal, you can see its phase change, Figure 3(g) is the modulated 2DPSK signal spectrum In the figure, the signal amplitude at the carrier frequency is 30000 at this time. The parameters of Levy noise are set, and the characteristic index α is 1.5, the skew parameter β is 0, the scale parameter σ is 1, the position parameter μ is 0, and the noise intensity D is 0.3. Combine the modulated 2DPSK signal with Levy noise to obtain the time-domain waveform of the noise-added signal shown in Figure 4(a). In a strong noise background, the time-domain waveform of the noise-added signal can be seen No valid information. From the spectrogram of the noise-added signal shown in Figure 4(b), the spectral amplitude at the carrier frequency is 30680.



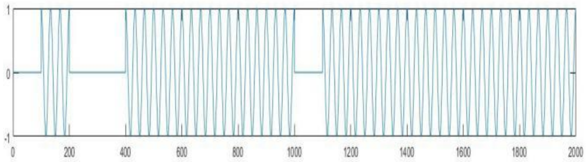
(a) Local carrier signal



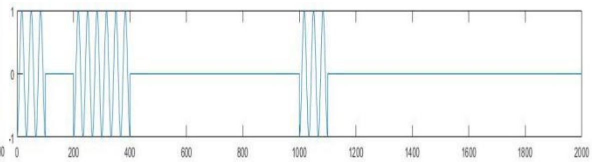
(b) Absolute code



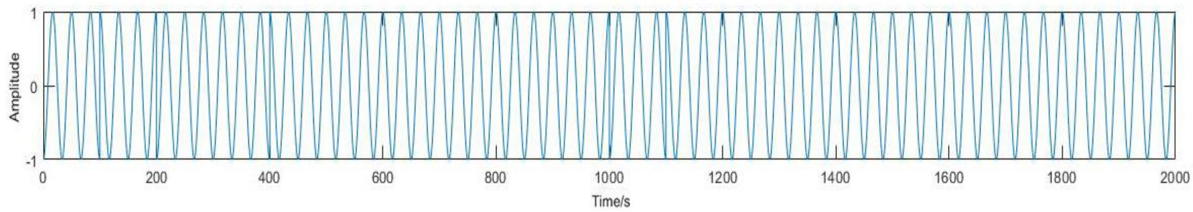
(c) Relative code



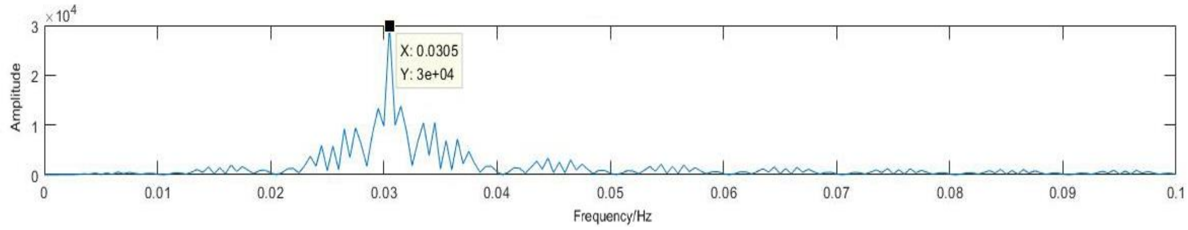
(d) Multiplying signal 1



(e) Multiplying signal 2

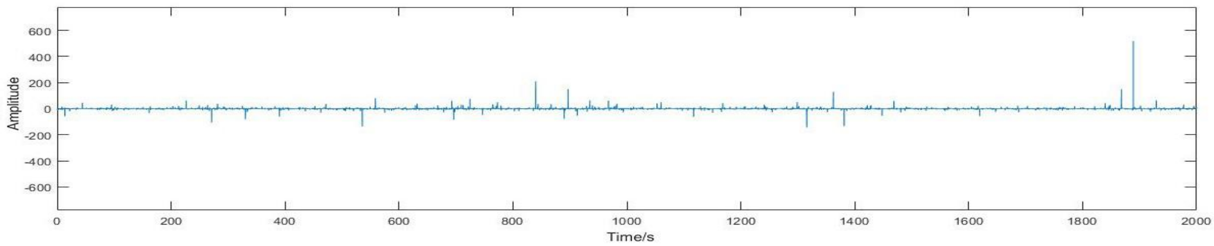


(f) Time domain diagram of 2DPSK signal

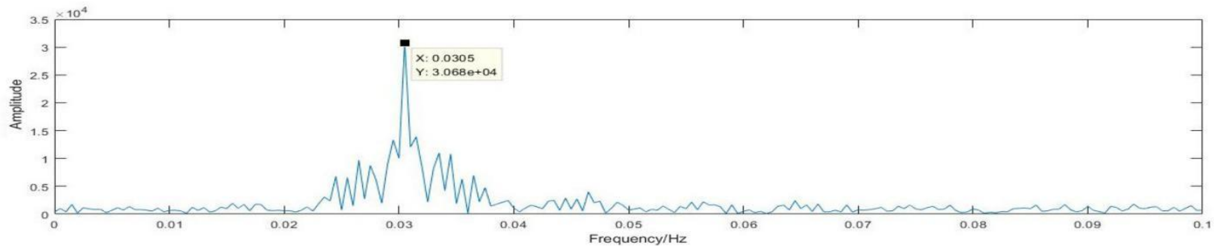


(g) Frequency domain diagram of 2DPSK signal

Figure 3: 2DPSK signal modulation signal diagram



(a) Time domain waveform of noise signal

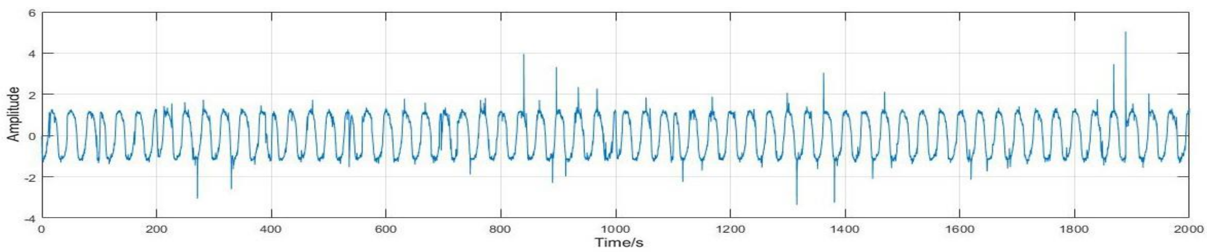


(b) Spectrogram of noise signal

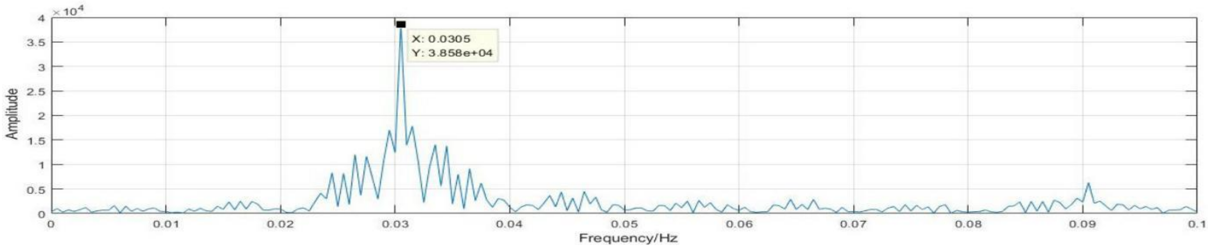
Figure 4: Time domain and frequency domain of noisy signal

5.2 Signal coherent demodulation process

The fourth-order Runge-Kutta algorithm is used for numerical simulation experiments, and the values of the parameters a and b of the stochastic resonance nonlinear system are obtained by the adaptive algorithm. The output signal is demodulated and analyzed using the coherent demodulation model of the stochastic resonance nonlinear system in Figure 2 to obtain the time-domain waveform and frequency spectrum after passing through the stochastic resonance system shown in Figure 5. From Figure 5(a), it can be seen that the output signal has a stochastic resonance phenomenon. The time-domain waveform at this time has been approximated as a periodic signal, the graphics are clear, and the transmitted information is more accurate. At this time, Levy noise with an intensity of D is not a negative factor in the signal transmission process, but has a positive effect on increasing signal energy. The amplitude of the output signal at the carrier frequency in Figure 5(b) is 38580, which is 1.26 times the amplitude of the noise-added signal at the carrier frequency in Figure 4(b), and the signal amplitude has been significantly improved. It shows that the use of the coherent demodulation model in Figure 2 can make the frequency spectrum amplitude at the carrier frequency increase significantly, and the application of the bistable stochastic resonance system can make the signal more accurately detected. Filtering out the useless noise outside the bandwidth is the effect of adding a band-pass filter. Figure 6 shows the spectrum after passing through the two models. Figure 6(a) shows the traditional coherent demodulation method after passing the band-pass filter. The spectral amplitude at the carrier frequency is 30690, which is reduced relative to the signal after adding noise. Figure 6(b) shows the frequency spectrum amplitude of the band-pass filter at the carrier frequency of 38690 after passing through the coherent demodulation model of the bistable stochastic resonance system. The output signal after filtering out the useless noise outside the bandwidth enters the multiplier and is multiplied by the local carrier. At this time, the frequency domain diagrams of the two models are shown in Figure 7. Figure 7(a) shows that the peak value of the spectrum after the traditional coherent demodulation method passes through the multiplier is 15350, which is at 2 times the carrier frequency. Figure 7(b) shows the spectrum amplitude of the coherent demodulation model of the cascaded stochastic resonance system at the carrier frequency of 18280 after the multiplier. The signal multiplied by the local carrier of the same frequency and phase passes through the low-pass filter and removes the high-frequency signal. It can be seen from the diagrams (b) and (d) of Figure 8 that only low-frequency signals exist at this time. The signal is sampled and judged, and the time-domain waveform of the output signal is obtained after demodulation to obtain the sampled and judged output signal diagram as shown in Figure 9. Comparing the output signal diagrams of Figure 9 (a) and (b) with the relative codes of Figure 3(c), it is found that the signal diagram output by the traditional coherent demodulation method produces more errors during transmission. The stochastic resonance system will suppress the noise energy and increase the signal energy, so the coherent demodulation model of the bistable stochastic resonance system will reduce the bit error rate of the system output. Perform code inverse transformation on the signal after sampling and decision to obtain the final demodulated signal diagram as shown in Figure 10. It can be seen that the coherent demodulation method using bistable stochastic resonance can effectively improve the quality of 2DPSK signals.

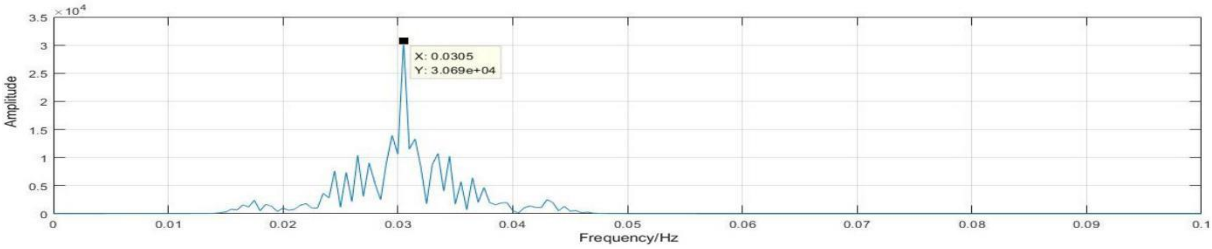


(a) Time domain waveform through the system

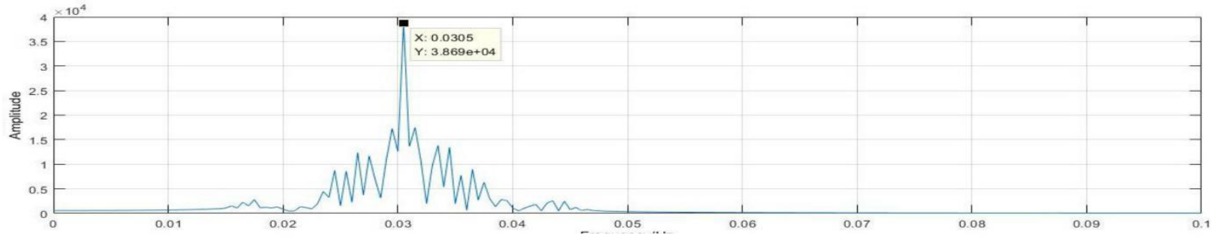


(b) Spectrogram through the system

Figure 5: Time and frequency domain graphs through stochastic resonance model

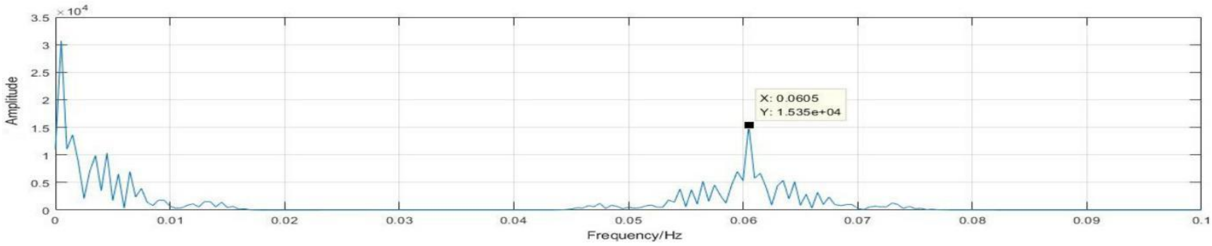


(a) Spectrogram through the model in Figure 1(b)

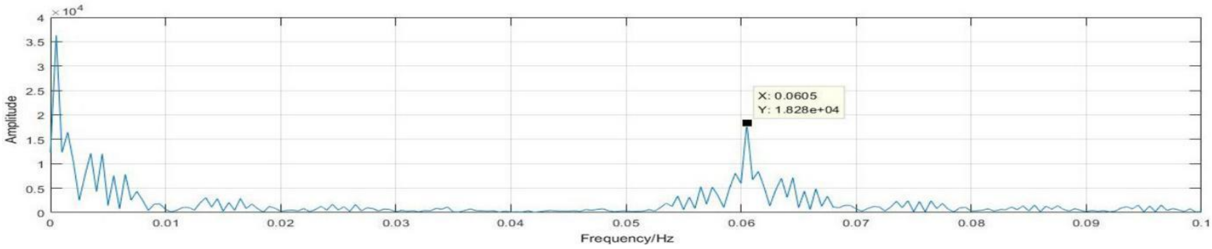


(b) Spectrogram through the model in Figure 2

Figure 6: Frequency domain graph after passing bandpass filters in two models

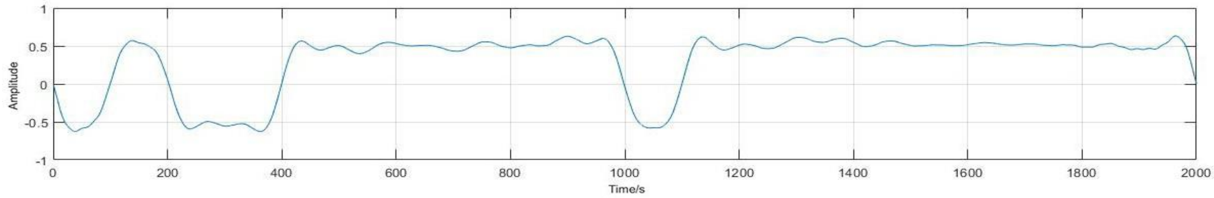


(a) Spectrogram after passing through the model multiplier in Figure 1(b)

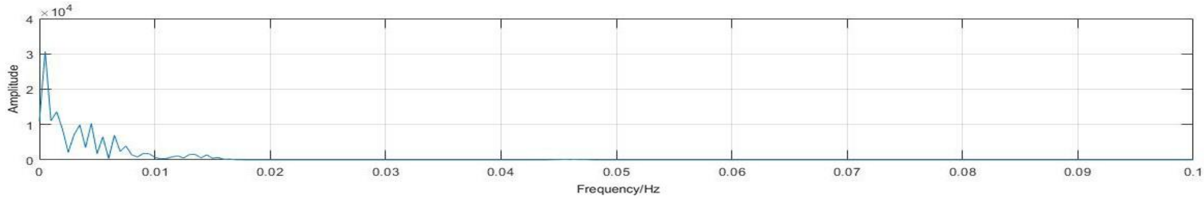


(b) Spectrogram after passing through the model multiplier in Figure 2

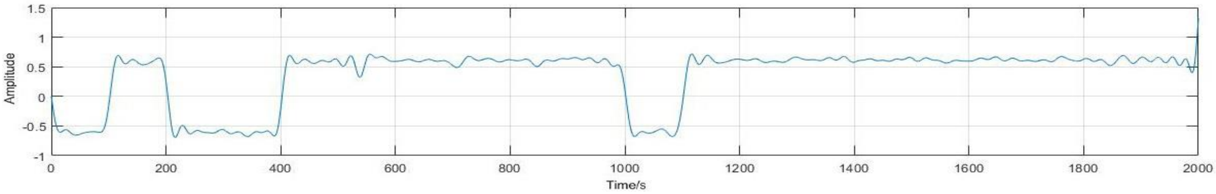
Figure 7: Frequency domain graph after passing the multipliers in the two models



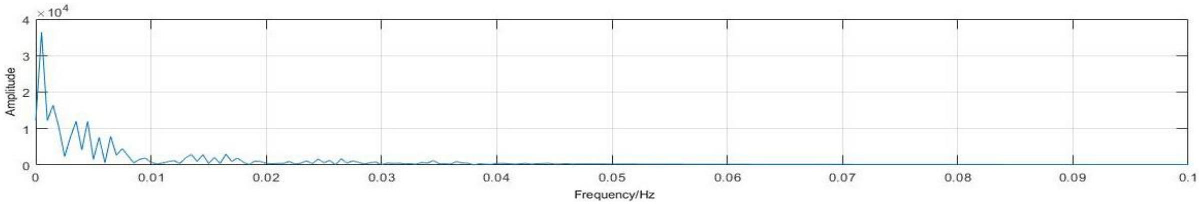
(a) Time-domain waveform through the model in Figure 1(b)



(b) Spectrogram through the model in Figure 1(b)

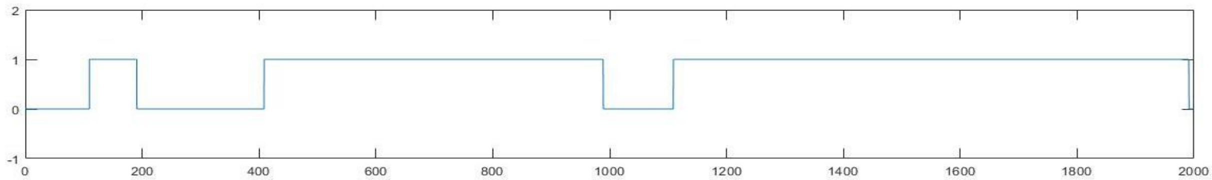


(c) Time-domain waveform after passing through the model in Figure 2

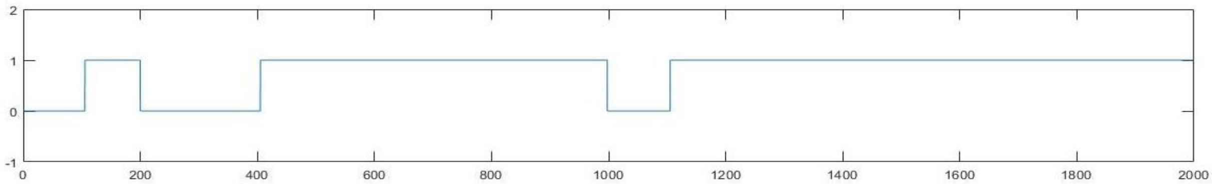


(d) Spectrogram after passing the model in Figure 2

Figure 8: Time and frequency domain graphs after passing low-pass filters in two models

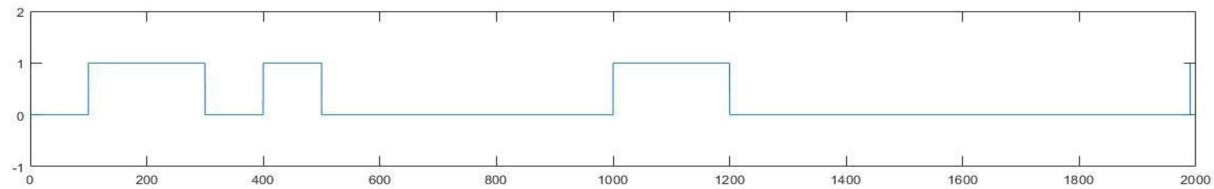


(a) Signal diagram through the model in Figure 1(b)

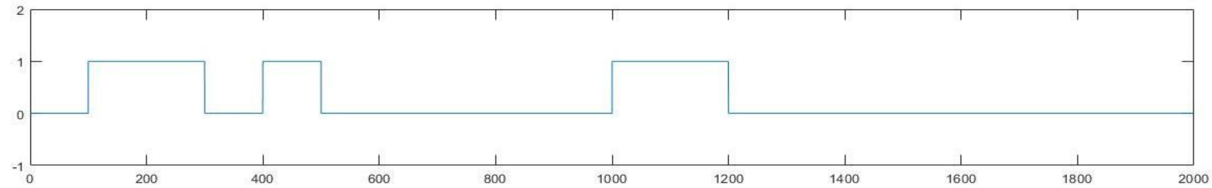


(b) Signal diagram after passing the model in Figure 2

Figure 9: The signal graph after sampling decision of two models



(a) Signal diagram through the model in Figure 1(b)



(b) Signal diagram after passing the model in Figure 2

Figure 10: Signal diagram after inverse transformation of two model codes

6. Conclusion

Based on the principle of stochastic resonance, this paper studies the stochastic resonance phenomenon of a binary digital signal passing through a nonlinear bistable system, performs a complete coherent demodulation process on the signal, and improves the output quality of the signal. In this paper, a strong impact Levy noise is added to the cascaded bistable stochastic resonance system to perform coherent demodulation of the 2DPSK signal. A comparative analysis is made from the time-domain waveform and spectrogram, and it is concluded that when the noise signal enters the nonlinear cascade After the stochastic resonance system model, stochastic resonance occurs. At this time, the time-domain waveform is approximately a periodic signal, which can be highlighted in the noise. The peak value of the spectrum after coherent demodulation through the bistable stochastic resonance system is 1.26 times the peak value of the output spectrum through the traditional coherent demodulation model, which shows that the coherent demodulation model of the bistable stochastic resonance system can output 2DPSK signals more accurately and usefully under strong noise background. information. The signal passes through the band-pass filter, multiplier and low-pass filter of the two models to more completely describe the coherent demodulation process of the 2DPSK signal, which improves the output quality of the signal.

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