Analysis of Anti-interference Performance of DS-PAM UWB TT&C Signal in Single-tone Interference

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Abstract. Using IR-UWB technique to TT&C system can greatly improve the anti-interference performance of TT&C signal. Aiming at the IR-UWB signal using in TT&C system, its BER performance in single-tone interference is analyzed. At the same time, the effect on the anti-interference performance of each parameter is also analyzed, and the parameter setting method which can improve the anti-interference performance can be obtained. The formula derivation and simulation results show that the IR-UWB signal has strong anti-interference performance in single-tone interference, the pulse width and pulse repetition period are the main factors that affect the anti-interference performance, so the BER performance of the signal can be improved by reasonably setting the signal parameters.

1 Introduction

With the development of Tracking, Telemetry and Command(TT&C) technology, the requirement to the performance of the TT&C system will be higher and higher. Currently the electromagnetic environment of free space is becoming increasingly complex, the anti-interference performance of the system needs to be improved. And the IR-UWB technology is a new kind of wireless communication technology, which use very narrow pulse signal for data transmission, and has strong anti-interference performance. It is known to be a revolutionary progress in the field of wireless communication[1,2]. Introducing the IR-UWB technology to the TT&C system can greatly improve the anti-interference performance of TT&C system.

Commonly, the interference that TT&C system faces can be divided into non-human interference and human disturbance. The non-human interference mainly contains natural interference, such as noise and the system self-interference. And human disturbance is a deliberate interference, including blocking interference, single-tone interference and partial band interference, etc. Its purpose is to destroy the enemy's communication[3,4]. Among them, the single-tone interference, also known as tracking interference, is a typical human disturbance. It has a great impact on the TT&C system, and can greatly decrease the BER(Bit Error Rate) performance of the system. The BER performance of TH-PPM signal in single-tone interference is analyzed and compared with DSSS signal in [5]. And the BER formula of DS-UWB signal in partial band interference and single-tone interference is shown and the related simulation analysis is conducted in [6].

In this paper, aiming at the single-tone interference that the IR-UWB TT&C signal faces, the BER performance of the carrier modulation DS-PAM-UWB TT&C signal is analyzed, and the effect on the BER performance of signal parameters such as the pulse width and the pulse repetition period are studied. Thus by flexibly setting the IR-UWB TT&C signal parameters, specific single-tone interference can be effectively circumvented, and the anti-interference performance of the TT&C system can be improved.

2 Signal Model

As to the TT&C system which has long distance transmission, the carrier modulation DS-PAM-UWB signal is usually used as the TT&C signal. The carrier modulation DS-PAM-UWB signal is an IR-UWB signal scheme that use pseudo-code and binary data together to modulate the pulse amplitude, and then conduct carrier modulation. Its expression is[7]:

$$s_{uwb}(t) = A \cdot \left[\sum_{n=-\infty}^{\infty} \sum_{j=0}^{N_s-1} d_n \cdot c_j \cdot p(t - nT_f - jT) \right] \cos(2\pi f_c t) \tag{1}$$

Where A is the signal magnitude, d_n is the binary data, c_j is the pseudo-code sequence, whose period is N_s, $p(t)$ is the UWB monopulse, T_f is the duration of one bit of data, that is the period of the pseudo-code, T is the pulse repetition period, and f_c is the carrier frequency.

The simulation waveform of the signal is shown in Fig. 1. Here, the information rate $R_b = 100\text{Kbps}$, the period of the pseudo-code $N = 1023$, the pseudo-code rate $R_c = 102.3\text{Mbps}$, the pulse repetition period $T = 1/R_c$, the UWB monopulse is rectangular pulse, whose width is $T_0 = T/5$, and the carrier frequency $f_s = 2.5575\text{GHz}$.

(a) Time-domain waveform (b) The enlarged figure

Fig. 1 DS-PAM-UWB signal waveform

We can know that the carrier modulation DS-PAM-UWB signal contains a number of narrow pulse envelope, the polarity of each pulse is determined jointly by the pseudo-code and data information. The Intra-pulse signal is the sinusoidal carrier signal, and the binary PAM modulation here turns to BPSK modulation to the carrier.

3 Performance Analysis

The IR-UWB system generally uses the correlation receiver to receive and demodulates the signal, wherein the main component is the correlator. Before the correlator, we assume that the pseudo-code synchronization, carrier synchronization, and bit synchronization are all accomplished, and the carrier has been removed by down-converting.

There are two inputs in the correlator, one is the received signal $r(t)$, the other is the template signal $s_t(t)$ which is locally generated. For DS-PAM-UWB signal, the locally generated template signal is essentially the pulse train modulated by pseudo-code. The expression of the template signal is[8]:

$$s_t(t) = \sum_{j=0}^{N_s-1} c_j \cdot p(t - jT) \tag{2}$$

Where. $c_j \in \{1, -1\}$ .So the output result of the correlator is:

$$y(\tau) = \int_{-\infty}^{\infty} r(t-\tau) \cdot s_t(t) dt = \int_{-\infty}^{\infty} r(t-\tau) \cdot \sum_{j=0}^{N_s-1} c_j \cdot p(t - jT) dt \tag{3}$$

And its Fourier transform is:

$$Y(\omega) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r(t-\tau) \cdot s_t(t) \cdot e^{-j\omega\tau} dt d\tau = \int_{-\infty}^{\infty} \left(\int_{-\infty}^{\infty} r(t-\tau) \cdot e^{-j\omega\tau} d\tau \right) \cdot s_t(t) dt = R(-\omega) \cdot S_t(\omega) \tag{1}$$

Where $R(\omega)$ and $S_t(\omega)$ are respectively the Fourier transform of the received signal and the template signal.

The transfer function of the correlator $|H(f)|$ is:

$$|H(\omega)| = \left| \frac{Y(\omega)}{R(\omega)} \right| = |S_t(\omega)| \tag{5}$$

That is:

$$\left|H(\omega)\right| = \left|\int_{-\infty}^{\infty}\sum_{j=0}^{N_s-1} c_j \cdot p(t-jT)\cdot e^{-j\omega t}dt\right| = \left|\int_{-\infty}^{\infty}\begin{bmatrix} c_0\cdot p(t)+c_1\cdot p(t-T)+c_2\cdot p(t-2T)+\cdots \\ c_{N_s-1}\cdot p[t-(N_s-1)T]\end{bmatrix}\cdot e^{-j\omega t}dt\right| = \left|T_0\cdot \sin c(\frac{\omega T_0}{2\pi})\right|\cdot\left|c_0+c_1\cdot e^{-j\omega T}+\cdots c_{N_s-1}\cdot e^{-j\omega(N_s-1)T}\right|$$

(2)

If the power spectral density of the interference signal entering the receiver is $G_J(\omega)$, the power of the output interference signal of the correlation receiver is:

$$G_{J\_out}(\omega) = G_J(\omega)\cdot\left|H(\omega)\right|^2 \tag{7}$$

Now assume that the system has only a single user and within the passband there is a single-tone interference signal whose magnitude is A and frequency is f_J, its expression can be shown as :

$$n_J(t) = A\cos(2\pi f_J t+\theta)$$

(3)

Where, θ is the initial phase of the single-tone interference signal.

If the power of the interference signal is $J = A^2/2$, so the bilateral power spectrum of $n_J(t)$ is [9,10] :

$$G_J(\omega) = \frac{J}{2}\left[\delta(f-\omega_J)+\delta(f+\omega_J)\right] \tag{9}$$

where， $\omega_J = 2\pi f_J$.

So from formula (7) we can know that the power of the output interference signal after demodulation is :

$$P_{J\_out} = \int_{-\infty}^{\infty} G_{J\_out}(\omega)d\omega = J\left|T_0\cdot \sin c(\frac{\omega_J T_0}{2\pi})\right|^2\cdot\left|\begin{matrix} c_0+c_1\cdot e^{-j\omega_J T}+c_2\cdot e^{-j\omega_J 2T}+\cdots \\ c_{N_s-1}\cdot e^{-j\omega_J(N_s-1)T}\end{matrix}\right|^2 \tag{10}$$

And the output power of the demodulated signal is：

$$P_{s\_out} = E_b^2 = E_p^2\cdot N_s^2 \tag{4}$$

Therefore, the SIR(Signal to Interference Ratio) of demodulation output signal is :

$$SIR = \frac{P_{s\_out}}{P_{J\_out}} = \frac{E_b^2}{J\left|T_0\cdot \sin c(\frac{\omega_J T_0}{2\pi})\right|^2\cdot\left|\begin{matrix} c_0+c_1\cdot e^{-j\omega_J T}+c_2\cdot e^{-j\omega_J 2T}+\cdots \\ c_{N_s-1}\cdot e^{-j\omega_J(N_s-1)T}\end{matrix}\right|^2} = \frac{E_p^2\cdot N_s^2}{J\left|T_0\cdot \sin c(\frac{\omega_J T_0}{2\pi})\right|^2\cdot\left|\begin{matrix} c_0+c_1\cdot e^{-j\omega_J T}+c_2\cdot e^{-j\omega_J 2T}+\cdots \\ c_{N_s-1}\cdot e^{-j\omega_J(N_s-1)T}\end{matrix}\right|^2}$$

(12)

So the BER of the system is :

$$P_{error} = Q(\sqrt{SIR}) \tag{13}$$

Where,. $Q(x) = \frac{1}{2}erfc(\frac{x}{\sqrt{2}}) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty}\exp(-\frac{t^2}{2})dt$

4 Impact of the signal parameters

Aiming at the specific single-tone interference, the impact on anti-interference performance of various signal parameters will be analyzed. Since the Q function is a monotonically decreasing function, in order to reduce the BER, we need to improve the demodulated output SIR, which requires a larger molecule and a smaller denominator in the formula (12). In the molecule of formula(12), it is obvious that the bigger E_p and N_s the better, but it is constrained by the actual conditions.

In the denominator of formula (12), there are mainly two formulas as :

$$\left|T_0\cdot \sin c(\frac{\omega_J T_0}{2\pi})\right|^2 \tag{5}$$

$$\left|c_0+c_1\cdot e^{-j\omega_J T}+c_2\cdot e^{-j\omega_J 2T}+\cdots c_{N_s-1}\cdot e^{-j\omega_J(N_s-1)T}\right| \tag{6}$$

As for the formula (14), we expect it smaller. It is a sinc function, whose value is 0 when $\omega_J T_0 = 2k\pi, k = 1, 2, \cdots$. So, while there is a single-tone interference whose angular frequency is $\omega_J = 2\pi f_J$, in order to improve the demodulated output SIR, we can select the pulse width T_0 of the rectangle pulse as :

$$T_0 = \frac{2k\pi}{\omega_J} = \frac{k}{f_J}, \quad k = 1, 2, \cdots \tag{7}$$

As for the formula (15) in the denominator, we also expect its value smaller. Through analysis, the value of it is greatly related to the pseudo-code, and has a cyclical change with the change of the pulse repetition period T, and its changing period is $1/f_J$. For a specific pseudo-code and specific single-tone interference, we can get the corresponding T when the formula has a minimum value (usually less than 1).

In addition, we consider a special condition. Generally, the cycle of pseudo-code $N_s = 2^L - 1$ is odd, and the difference between the number of 1 and -1 is 1. So we can select the value of T to meet:

$$f_J \cdot T = k, k = 1, 2, \cdots \tag{17}$$

So $e^{-j2\pi f_J T} = 1$ and thus the value of the formula is 1. It is not always the global minimum value, but is a local minimum. And at this time, the output SIR is :

$$SIR = \frac{E_p^2 \cdot N_s^2}{J\left|T_0 \cdot \sin c(\frac{\omega_J T_0}{2})\right|^2} \tag{18}$$

It should be noted that the above derivation is based on the assumption that the down-conversion has been accomplished, and f_J is for the non-carrier UWB signal. As for carrier modulation UWB signal, f_J refers to the difference between the interference frequency and the carrier frequency.

In summary, when there is a single-tone interference whose frequency is f_J, in order to reduce the demodulation output BER and improve the anti-interference performance, we can select appropriate values of T_0, T and other parameters. Among them, the value of T_0 needs to meet $T_0 = \frac{k}{f_J}$, and the value of T can be the minimum points of the formula (15).

5 Simulation analysis

Now simulation analysis is carried out using MATLAB. The signal parameters are set as follows: the information rate $R_b = 1\text{Mbps}$, the period of pseudo-code (m sequence) $N_s = 31$, the pseudo-code rate $R_c = 31\text{Mbps}$, one bit of pseudo-code corresponds to one pulse, the pulse repetition period $T = 1/R_c$, the single pulse signal is rectangular pulse, whose width is $T_0 = T/5$, the carrier frequency $f_c = 2.48\text{GHz}$. The received signal contains the UWB signal and the single-tone interference whose frequency is $f_J = 2.5\text{GHz}$. Correlation reception process is adopted. So when the SIR changes, its BER curve of the carrier modulation DS-PAM UWB signal is shown in Fig. 2.

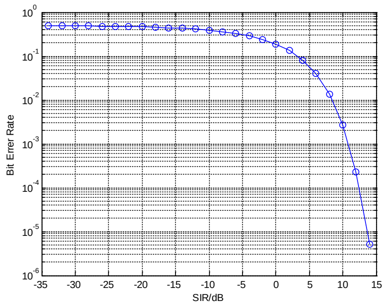

Fig. 2 BER curve of the UWB signal in single-tone interference

We can know that, as the SIR increases, the BER gradually decreased. When $SIR = 14dB$, the BER can reach the order of 10^{-5}.

Now we discuss the impact of parameter T_0. We can know from formula (16), the value of formula (14) can be close to 0 by selecting an appropriate value of T_0. Now we use MATLAB to make a simulation. The UWB signal parameters keep unchanged, the pseudo-code rate $R_c = 31\text{Mbps}$, the period $N_s = 31$, and the pulse repetition period $T = 1/R_c$, the carrier frequency $f_c = 2.48\text{GHz}$, the frequency of the single-tone interference is set $f_J = 2.605\text{GHz}$, the input SIR is set $-20dB$. Then for different pulse widths T_0, the BER curve is shown in Fig. 3.

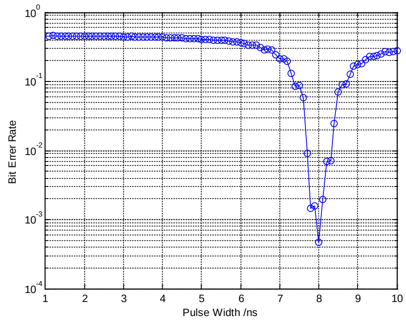

Fig. 3 BER curve of different T_0

We can know from the above figure that the BER of the signal reaches the minimum at $T_0 = 8\text{ns}$. Since the relative frequency of the single-tone interference is $f_J' = 0.125\text{GHz}$, so $T_0 \cdot f_J' = 1$, which completely corresponds with the conclusion of formula (16).

And now we discuss the impact of parameter T. We can know through the above analysis, the smaller the value of formula (15), the larger the output SIR, and the lower the BER. For a specific pseudo-code and specific single-tone interference, the corresponding T when the formula has a minimum value can be found through simulation. In addition, there is also a simple method, letting T meet $f_J \cdot T = k,\ k = 1, 2, \cdots$, and a lower BER can be obtained. Now we use MATLAB to make a simulation. The UWB signal parameters keep unchanged, the pulse width $T_0 = 2\text{ns}$, the pseudo-code period $N_s = 31$, the carrier frequency $f_s = 6.4\text{GHz}$, the frequency of the single-tone interference is set $f_J = 6.50204\text{GHz}$, and the input SIR is set $10dB$. Then for different pulse repetition period T, the BER curve is shown in Figure 4.

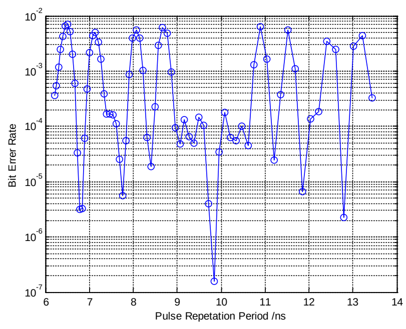

Fig. 4 BER curve of different T

The above figure shows that the BER of the UWB signal have minimum values at $T = 6.8\text{ns}$ $T = 12.8\text{ns}$ and $T = 9.8\text{ns}$, while the lowest BER is at $T = 9.8\text{ns}$. Among them, $T = 6.8\text{ns}$ and $T = 12.8\text{ns}$ are the minimum point of formula (15), and $T = 9.8\text{ns} = 1/f_J$, corresponding with formula (17).

6 Conclusion

Taking the typical DS-PAM-UWB TT&C signal as the object, aiming at the single-tone interference, the anti-interference performance of the signal is analyzed by theoretical derivation and MATLAB simulation. And the impacts on the performance of various signal parameters are also analyzed. Results show that there are large impacts on BER result from pulse width T_0 and pulse repetition period T. In practice, the parameters can be set or changed according to the frequency of the interference signal, so as to avoid single-tone interference, reduce the BER, and thus ensure the normal operation of the TT&C system.

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