Several Strategies for Anti-Multiple-Access Interference of Ground Equipment in Spread Spectrum Measurement and Control

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Abstract. In this paper, the inter-symbol interference problem of multi-objective mode for single-station measurement of ground equipment in spread spectrum measurement and control is obtained from the autocorrelation, cross-correlation, primitive polynomial selection method and three-object code between 10-level m-sequence and Gold code. Interference test and other aspects have been analyzed and discussed. Combined with the problem of small satellite star time-sharing signal level changes causing wrong lock and long time of re-trapping, the strategy of using ground-spread measurement and control equipment is proposed.

1. Introduction
In recent years, spread spectrum technology has been gradually applied in the field of space measurement and control due to its outstanding advantages in utilizing channel capacity, improving ranging accuracy, and no blurring distance and code division multiple access. It changes the single mode of the past single station survey target, and can be flexibly configured to achieve multiple modes such as multi-station survey target and single-station multi-target, especially for single-station multi-target, due to the reduction of payload and maximum. The distinctive features of the use of frequency bands and improved launch efficiency have been applied to some small satellites. The test results are good. Only one outstanding problem needs to be solved: multi-target interference between multiple targets, which is commonly referred to as expansion. Inter-frequency code interference problem.

2. Method of selecting primitive polynomial
2.1. Spread code correlation
The traditional frequency division signal capture uses the phase-locked loop to capture and track the residual carrier. Since the frequency band is strictly allocated, the interference signal is difficult to enter the narrow band of the phase-locked loop, so the interference problem is not prominent. The spread spectrum signal uses the search and detection correlation peaks to achieve the acquisition of the carrier and the spread code. Since the uplink and downlink carriers have the same frequency, the frequency band is wide, if the cross-correlation of the spread codes between the targets is not very high. When it is good, it is easy to make a wrong lock. For example, the ground channel A channel is locked on the spread spectrum signal of the target B. In severe cases, the A channel can even demodulate the telemetry information of the target B. This is a phenomenon we do not want to see. However, it is also an insurmountable engineering problem under the current code division system.
2.2. Method for generating spreading code

At present, the field of measurement and control also adopts the DS technology which is very mature in engineering. The spreading code also adopts the balanced Gold code, and the Gold code is compounded by two preferred m sequences. What needs to be considered is the method of generating the Gold code, which involves the selection of the m-sequence primitive polynomial and the initial phase. For the convenience of description, we take the short code generation method of the US GPS as an example.

GPS C/A code - short code is composed of two 10-level homologous m-sequences. The m sequence is generated using a linear shift register, which is typically characterized by a characteristic polynomial \( F(x) \). Any level of the 10-level linear shift register satisfies the following linear recursive relationship:

\[
a_j = \sum_{i=1}^{10} c_i a_{j-i}
\]

\[
\begin{align*}
    a_{j-1} &= a_j x \\
    a_{j-2} &= a_{j-1} x = a_j x^2 \\
    M &
\end{align*}
\]

Introducing the shift operator \( x \), substituting into formula (1) gives:

\[
a_j = c_1 a_j x \oplus c_2 a_j x^2 \oplus \Lambda \oplus c_{10} a_j x^{10}
\]

Because the feedback logic of the shift register is definitely present, ie \( c_0 = a_1 = 1 \), so:

\[
1 = c_0 = a_1 = c_1 x \oplus c_2 x^2 \oplus \Lambda \oplus c_{10} x^{10}
\]

That is,

\[
0 = c_0 \oplus c_1 x \oplus c_2 x^2 \oplus \Lambda \oplus c_{10} x^{10} = \sum_{i=0}^{10} \oplus c_i x^i
\]

Let: \( F(x) = \sum_{i=0}^{10} c_i x^i = 0 \)

For a 10-level shift register, \( 2^{10} - 1 = 1023 \) is a prime number. The first condition is satisfied, and the irreducible polynomial, that is, the primitive polynomial has 60, so there are 60 m sequences of the same level of the 10th. The m sequence has good autocorrelation properties, and its normalized autocorrelation function is:

\[
R(\tau) = \begin{cases} 
1, & \tau = 0 \mod(2^{n-1}) \\
\sqrt{2^{n-1}}, & \tau \neq 0 \mod(2^{n-1})
\end{cases}
\]

taking a double value, when \( n=10 \), \( 1/2^{10}-1=1/1023 \) is much smaller than the autocorrelation peak 1, so it is easy to search for the autocorrelation peak of the m sequence when the spreading code is captured. However, the cross-correlation of the m-sequence is not ideal, and the cross-correlation function takes multiple values, and the cross-correlation peak is large, as shown in Table 1.
Table 1. Parameters related to the m-sequence cross-correlation function

| Series \(n\) | Number of primitive polynomials \(J_r\) | Code length \(L_p\) | General sequence cross-correlation peak \(|R_C|_{\text{max}}\) | Preferred sequence cross-correlation peak \(|R_Y|_{\text{max}}\) |
|---|---|---|---|---|
| 5 | 6 | 31 | 0.29 | 0.290 |
| 6 | 6 | 63 | 0.36 | 0.270 |
| 7 | 18 | 127 | 0.32 | 0.134 |
| 8 | 16 | 255 | 0.37 | 0.129 |
| 9 | 48 | 511 | 0.32 | 0.065 |
| 10 | 60 | 1023 | 0.37 | 0.064 |

The cross-correlation peak of the ordinary 10-level m-sequence of Table 1 is 0.37, which cannot satisfy the requirement of code division multiple access. However, the m-sequences in the same-type m-sequence that can satisfy the two-two cross-correlation values are called preferred sequences, and they are mutually the relevant peaks are:

\[
|R_Y|_{\text{max}} = \begin{cases} 
\left(\frac{2^{(n+1)/2} + 1}{2^{n-1}}\right), & \text{n is odd} \\
\left(\frac{2^{(n+2)/2} + 1}{2^{n-1}}\right), & \text{n is even}\end{cases}
\]  

(3)

When \(n=10\), the cross-correlation peak of the preferred sequence obtained by Formula 3 is \(65/1023 \approx 0.064\), which is the same as the data of Table 1. Such a sequence can satisfy the requirement of code division multiple access, but the number is too small, and the statistics show that the number of preferred sequences in the 10-level m sequence does not exceed seven. The Gold code solves this problem well. It uses two m-sequences with the same code length and the same code clock as the subcodes. The change of the relative displacement of the two preferred sequences can give a new one. Gold code, when the relative displacement is \(2^{n-1}\) bits, you can get a family of \(2^{n-1}\) Gold codes, plus two preferred sequences themselves, there are \(2^{n+1}\) Gold codes, so there are 1025 Golds in the 10th order m sequence. The code is fully capable of meeting general engineering needs.

The Gold code inherits the cross-correlation of the preferred m-sequence, and its cross-correlation function takes only three values, which is:

\[
R_G = \begin{cases} 
-1 & , t(n) = -t(n) \frac{1}{2^{n-1}} \\
\left[\frac{2^{(n+1)/2} + 1}{2^{n-1}}\right] & , \text{n is odd} \\
\left[\frac{2^{(n+2)/2} + 1}{2^{n-1}}\right] & , \text{n is even, and } n \mod(4) \neq 0
\end{cases}
\]  

(4)

When \(n=10\), the cross-correlation peak of the Gold code obtained by Equation 4 is \(65/1023\), which is the same as the cross-correlation peak of the preferred sequence, and can satisfy the code division multiple access requirement.

2.3. Selection of primitive polynomial

There are two methods for generating Gold code: one is to connect two preferred subcodes into a 2n-level linear shift register, and the two subcodes are respectively set to the initial phase; the other is to connect the two subcodes in parallel and then add 2, two. The initial phase of each subcode is the same,
and a fixed initial phase is set at the time when the first pulse control is received, so that only one sub-code is subjected to two-stage tapping, and then an equivalent sequence with the original m-sequence can be generated. By shifting the equivalent sequence as a subcode, you can generate Gold codes of different initial phases, while the other subcode does not need to move the initial phase, as shown in Figure 1. The effect is the same, but it is simpler to implement. At the same time, since the initial phase of a subcode is fixed, the spreading code assembly is simplified, and the GPS adopts the second generation method. Currently, the ground spread spectrum measurement and control device also adopts this method.

The definition of primitive polynomial and initial phase of terrestrial spread spectrum measurement and control equipment has its particularity. Taking the two subcodes of GPS C/A code as an example, the primitive polynomials of subcode A and subcode B are \(1+x^2+x^3+x^6+x^8+x^{10}\) and \(1+x^3+x^{10}\), which is the usual positive sequence, with level 0 being the total feedback line, followed by level 1, and level 10 being the last stage output. The ground spread spectrum measurement and control equipment is arranged in reverse order, the 0th level is the total feedback line, followed by the 10th level, and the last stage output is the 1st level, as shown in Figure 1. Therefore, the expression of its primitive polynomial should be \(1+x^1+x^2+x^4+x^7+x^8+x^{10}\) and \(1+x^7+x^{10}\), and its primitive polynomials are 3515 (11101001101) and 2011 (10000001001) in octal code. The initial phase of subcode A is fixed, and the initial phase of subcode B is selected by two levels of taps.

3. Ground equipment anti-code interference test

We take the ground single station to three target measurement and control as an example. The ground receiving downlink signals are threshold level and medium intensity level respectively. The three target stars A, star B and star C downlink signals are generated by satellite simulator, respectively simulating simultaneous And several states in time.

From Table 2, when the downlink signal is the threshold level and the ground equipment receives the medium strong level at the same time, the test result is good, and the index requirement of the spreading code capture is less than 2 seconds, but the medium-strong signal is transmitted in the three targets. At the same time, both the wrong lock phenomenon and the different time of re-catch time are repeated, and the same test described above is repeated, and the result is basically the same as the data of Table 2, especially when the interference signal is first transmitted, the target signal is greater than the latter two target signal levels by 15 dB. At the time, the phenomenon of too long a recapture occurred very frequently.

![Figure 1. Schematic diagram of the 10-level Gold code primitive polynomial generation](image-url)

The error lock phenomenon occurs, indicating that the interfered channel is locked on the cross-correlation peak of the interference signal. In other words, the cross-correlation peak of the
interference signal is larger than the capture threshold of the interfered channel. The cross-correlation peak of the 10-level Gold code mentioned above is \( \frac{65}{1023} \), so the interference signal is at the threshold level, the cross-correlation peak is about 12 dB lower than the capture threshold, so there is no error lock, and the interference signal is medium-high power. When flat (greater than the threshold level of 20dB), the cross-correlation peak is about 20-12=8 dB higher than the capture threshold, so it is mis-locked.

| Strength of downstream signal | Test results |
|------------------------------|--------------|
| Threshold level              |              |
| the same time                | good         |
| A-B-C                        | good         |
| B-A-C                        | good         |
| C-A-B                        | good         |
| Medium strong level          |              |
| (greater than the threshold level of 20dB) |          |
| the same time                | good         |
| A-B-C                        | The re-trapping time of the spreading codes of B and C is 22 seconds and 25 seconds respectively. |
| B-A-C                        | The re-trapping time of the spreading codes of A and C is 6 seconds and 2 seconds respectively. |
| C-A-B                        | The re-trapping time of the spreading codes of A and B is 10 seconds and 2 seconds respectively. |

4. Ground equipment anti-code interference use strategy

The indicator stipulates that the ability of inter-code interference between ground equipment channels is 10 dB. Therefore, when the three targets are simultaneously controlled and controlled, the power between the channels must not exceed 10 dB. Usually, the telemetry and ranging channel power ratio of the same target is set to 4:1. (6dB), this is the most common strategy for ground equipment to resist inter-code interference. After using this strategy, regardless of the signal level strength, multi-target simultaneous measurement and control time code interference does not affect, as shown in Table 2 data. However, for some small satellites, the separation of satellites and arrows is carried out separately. In other words, the transmission of each target signal is sequential, and the satellite pattern changes due to different attitudes after satellites, causing ground reception. The signal level between channels is different. It is possible that the previous target signal is greater than 10 dB later than the target signal. Therefore, for this type of target measurement and control, the error lock phenomenon is theoretically difficult to avoid because it is related by code. Sexually determined - the cross-correlation peak of the 10-level Gold code is only 12 dB smaller than the autocorrelation peak. The key to the problem is how the interfered channel can quickly recapture the normal signal when the normal signal arrives.

In this context, an effective solution is to change the tracking decision threshold for each channel. We know that for the frequency division system, the tracking synchronization after signal acquisition is maintained by the narrow-band tracking filter characteristic of the phase-locked loop. At present, the ground-based equipment of the spread spectrum measurement and control keeps the signal synchronization after the acquisition by using the sliding correlation detection mechanism: After the signal is captured by the spreading code ring, the tracking decision branch is still continually performing a sliding correlation operation with the receiving external signal, that is, the local code of the mobile decision branch performs a sliding correlation operation with the received external signal, if the correlation peak is larger than the original correlation peak. The threshold, that is, the decision signal is mis-locked, and the spreading code ring immediately exits the tracking state and restarts the search. The current tracking decision threshold is set to 8 times (9 dB) that the sliding correlation peak is larger than the original correlation peak. The 9 dB decision threshold can effectively reduce the...
false judgment, but raises the threshold of recapture after the wrong lock. The test shows that if
Reducing the tracking threshold to 2 times (3 dB) can keep the signal from being locked after being
locked, so it can greatly reduce the time to recapture the normal signal after the wrong lock - if the
interference signal is not greater than 15dB of the normal signal, can quickly recapture the target, the
recapture time is less than 2 seconds. As mentioned above, when the interference signal is greater than
15dB of the normal signal, the phenomenon of long recapture occurs very frequently. After changing
the tracking threshold, the number of occurrences of the phenomenon is significantly reduced, but it
can still occur. This is theoretically possible. Explain: The autocorrelation peak of the normal signal is
12 dB larger than the cross-correlation peak of the mis-lock, plus the tracking decision threshold of 3
dB, equal to 15 dB, just offsetting the interference signal by 15 dB larger than the normal signal,
which is in a critical state, so it is not enough Make the wrong lock status change.

5. Conclusion
The above problem of using the ground equipment in the problem of long-distance lock caused by
multi-target inter-symbol interference and the long-recovery time problem cannot solve the problem
fundamentally. One of the fundamental solutions can be modified by using the spread-spectrum
baseband software. Data Frames - Conditions for adding target recognition and determining locks in
telemetry frames and ranging frames.

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