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Research of Acquisition Algorithm of P Code in Navigation Signals

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Abstract: Aimed at solving the problems of Precision code's complex acquisition procedures and its long acquisition time in satellite navigation, this paper makes an architecture analysis of the commonly used direct acquisition algorithms of Precision code, making an improvement of the common local pseudorandom code based glide Fast Fourier Transform acquisition architecture. Besides those, it also puts forward a local pseudorandom code based fixed Fast Fourier Transform acquisition architecture and improved pseudorandom code superposed Fast Fourier Transform acquisition architecture. Compared with common local pseudorandom code based glide Fast Fourier Transform acquisition architecture, the methods proposed efficiently simplify acquisition complexity and shorten acquisition time. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Precision code (P code), Direct Acquisition, Fast Fourier Transform (FFT), Acquisition Time.

1. Introduction

Direct acquisition of P code is an important component of satellite navigation and positioning receivers. P code is the precise ranging code transmitted by navigation satellite. Due to the fact that P code has longer pseudorandom (PN) code period and relatively high code rate, both its anti-interference and anti-interception performances are higher than C code, leading to versatile military uses [1, 2]. In the second-generation BeiDou (BD-2) system, the precise ranging code is a PN code with period of 7 days to accommodate for Precise Positioning Service (PPS).

Because P code's code period is relatively longer, direct search of P code's code phase requires very long search time, unable to satisfy the demands of navigation and orientation [3, 4]. Thus, direct acquisition of P code needs some certain initial conditions, that is, consumers need to know some priori information beforehand such as approximate time of current moment or satellite almanac. With the priori information, time uncertainty spectrum acquiring P code can be narrowed.

However, on account of P code's high code rate and long code period, in certain time uncertainty spectrum, calculation amount required to conduct acquisition is much higher than that of C code, since direct use of C code acquisition algorithm to conduct P code acquisition takes very large amount of hardware recourse and quite a long time to fulfill it [5]. Though with code element reconstruction method exploited data processing amount can be reduced, it would also give rise to correlated

Signal/Noise Raito (SNR) loss. So how to decrease acquisition time of P code and simplifying computational complexity in condition of correlated SNR guaranteed is the focus of the research of direct acquisition technique of P code.

2. Common P Code Acquisition Algorithm

Since code period of P code is very long, direct acquisition requires many code phases, therefore serial acquisition algorithms are not suitable for direct acquisition of P code. Current direct acquisition algorithms of P code mainly contain two types. One is parallel correlative method, that is, to solve the problem of P code's wide search scope parallel correlator searches multiple Doppler frequencies or multiple code phases in one time. Parallel correlative method performs quite well on acquisition, fitting direct acquisition of P code in low SNR, but its structure is complicated, consuming considerable energy. Another algorithm is code element reconstruction method, which initially processes code element to be searched, cutting p code's code period to reduce calculation amount. Code element reconstruction method is relatively simple, with lower computational volume. Nonetheless due to the fact that it processes code element, the former good correlation of code element has changed, decreasing correlative SNR, making it degenerate in low SNR. Below will show the analyses of the common parallel correlative method and code element reconstruction method.

2.1. Parallel Correlative Method

Parallel correlative method often utilizes mass parallel correlators or long-ordered matched filter to realize direct acquisition of P code [6]. In view of structures common parallel correlative methods are constituted by FFT based PN code phase parallel search, time-domain correlation combined FFT algorithm and matched-filter combined FFT algorithm. The three algorithms require mass parallel calculation, and high standards for hardware. As very large scale integrated circuit's development, the algorithms have been widely implemented in satellite navigation and orientation receiver.

1) FFT based PN code phase parallel search method (abbreviated for FFT direct acquisition method).

The algorithm flow of FFT based PN code phase parallel search is shown as Fig. 1 [7].

In FFT based PN code phase parallel search algorithm, length-N input signal is zero-padded to generate length-2N local PN code. Then receiver makes FFT of local PN code and input signal, whose results are sent to conjugate multiplication. If through detection and judging following IFFT, there is no signal, then use logical control unit transferring frequency or local PN code phase to continue to search till all the search-grids are traversed. To further shorten acquisition time, usually multiple FFT search method is adopted, that is, while receiving input signal, the algorithm correlates multiple local PN codes with the input, which finishes multiple code phase parallel searches in one time.

2) Time-domain correlation combined FFT algorithm [8].

Time-domain correlation combined FFT algorithm refers to the method that first correlates input signal and local PN code in time domain, then analyzes partial correlation value of time-domain correlator output using FFT, which architecture is shown as Fig. 2.

The widely utilized in Global Positioning System (GPS) satellite navigation and orientation Y-EXPRESS chip just implements the acquisition method, allowing one acquisition channel to search 511 code phases simultaneously, conducting FFT to the segmental integrated-dump results, and detecting 64 frequency shifts at the same time. In receiver application, multiple Y-EXPRESS chips are used to further curtail acquisition time.

3) Matched-filter combined FFT algorithm [9].

Matched-filter combined FFT algorithm is similar with time-domain correlation combined FFT, making frequency analysis by sending several short-time matched filter outputs to FFT units to complete Doppler frequency parallel search. The structure is shown as Fig. 3.

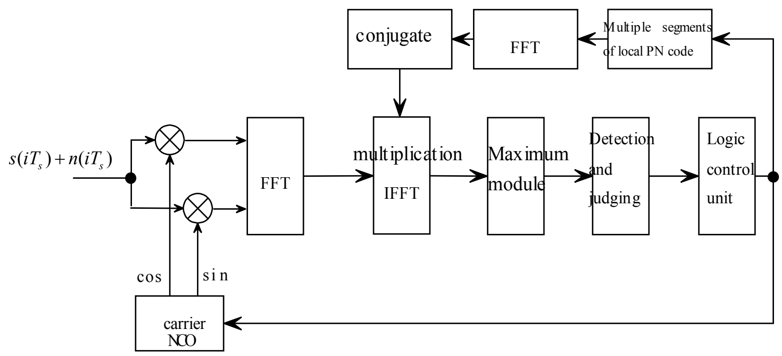

Fig. 1. FFT based P code acquisition flow.

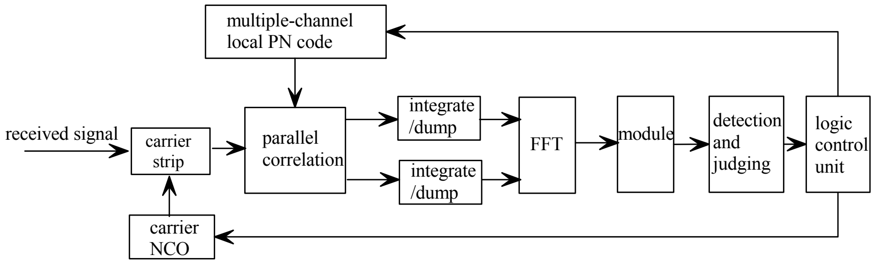

Fig. 2. Time-domain correlation combined FFT algorithm flow.

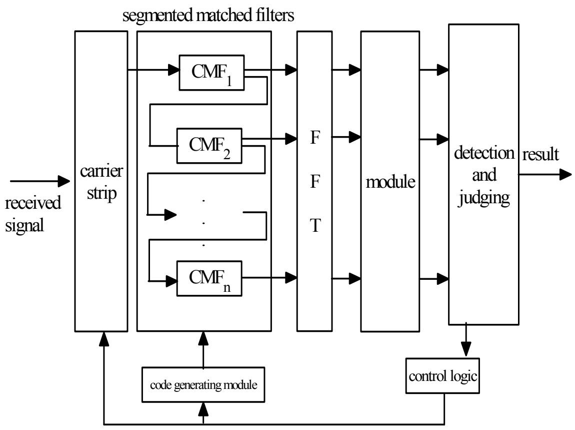

Fig. 3. Matched-filter combined FFT algorithm flow.

DirAc ASIC employs the algorithm to realize GPS P code sequence direct acquisition. The chip consists of 16 short-time matched filters, every one of which provides 0.625 ms correlative integrated time. Output of matched filters is sent to FFT units for frequency analysis to complete Doppler frequency detection.

3. Research on FFT Based Direct Acquisition Algorithm of P Code

From former discusses, FFT direct acquisition algorithm is a realization algorithm of code element parallel correlation, which has a rapid acquisition speed. Similar with C code FFT fast acquisition algorithm, FFT based direct acquisition algorithm of P code first parallel searches code phase, and serially searches Doppler frequency. But P code's code phase is more, so one correlation can not search all the code phases, which indicates segmented searches of code phases in the whole time uncertainty spectrum are necessary. Common FFT direct acquisition algorithm of P code flow is shown as Fig. 4.

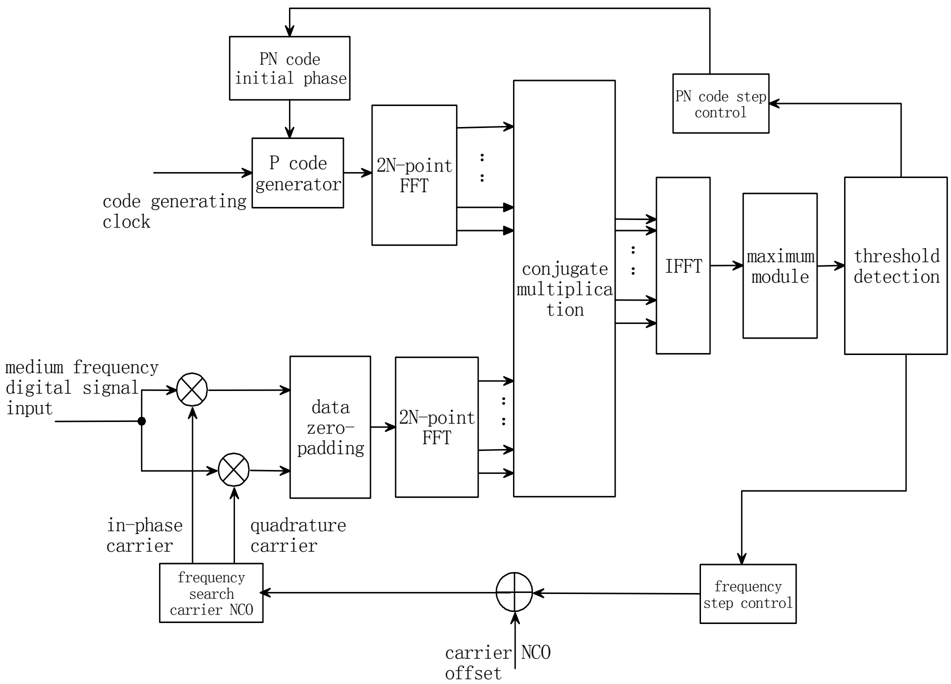

Fig. 4. FFT Direct Acquisition Algorithm of P Code Flow.

3.1. Common Local PN Code Based Glide FFT Acquisition Architecture

Assuming that after sampling input signal in the whole code phase search spectrum changes to L points, one FFT computation searches N code phases, which requires $M = L / N$ FFT. The input signal f_1 corresponds to PN code $\{g_i, 1 \le i \le M\}$ in the time uncertainty spectrum. Incidentally searching the whole time uncertainty spectrum refers to correlating f_1 with $g_i, 1 \le i \le M$. As M is relatively large, after taking input dynamics on condition that the saved received signal f_1 is correlated with local PN code in the whole time uncertainty spectrum, the Doppler frequency of current signal may not equal to the Doppler frequency of f_1 signal, unable to transfer to real-time tracking when signal is searched. So in receiver, real-time receiving should be adopted to acquire signal. When acquiring received signal, the corresponding code phase relations of satellite signal and local PN code are shown as Fig. 5.

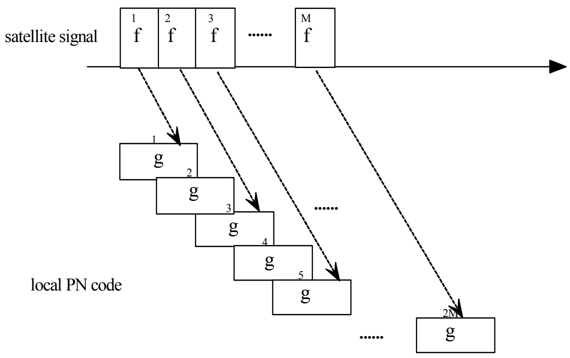

Fig. 5. Diagram of gliding relations of satellite signal and PN code signal.

Let input satellite signal be F, and local PN code G. Use the result of circular convolution instead of linear convolution, and choose sub-segment of local PN code twice the length of satellite signal sub-segment. Next, satellite signal is correlated with local sub-segmental PN code after zero-padding. Zero-pad input N-point signal to $2N$ points in accordance with the process of FFT's point zero-padding, which arrives at input signal sub-sequence $\{f_i, 1 \le i \le M\}$. If every sub-segment points of local PN code is $2N$ and there are $2M$ segments of $\{g_j, 1 \le j \le 2M\}$ in every N points of overlapped PN code between each sub-segments, then the code phase glide procedures in one frequency search unit are below:

Step 1. Receive the first segment input signal f_1, remove the carrier, and send it to cache after FFT.

Step 2. Extract the first local PN sequence g_1, and send it to cache after FFT.

Step 3. Make conjugate multiplication of the two FFT results. Then conduct IFFT, setting the first half as the correlative value.

Step 4. If correlative peak value exceeds the threshold, it is taken as the sign that the signal is acquired.

Step 5. If no correlative peak value exceeds threshold, it is considered that in this part of time uncertainty no PN code matches input signal.

Step 6. Receive the second input signal f_2, move local PN code to g_3, and repeat the former procedures till the whole time ambiguity has been searched.

It is learned from former search procedures that every time MN time uncertainty spectrum is searched, M length-N signals should be zero-padded to $2N$ to correlate with M length-2N local PN codes.

3.2. Improved Local PN Code Fixed FFT Acquisition Architecture

To reduce calculation amount and maintain local PN code fixed, glide input signals should be correlated with local PN code. Supposing FFT correlative points are $2N$, according to the way how FFT processes the points, input signals are divided into N-point segments individually to be zero-padded, getting input sub-sequence $\{f_i, 1 \le i \le M\}$. With reference to time uncertainty spectrum, set PRM module, making the last segment of PN code g_M within the output spectrum as local PN code. Keep local PN code constant, and correlate g_M with received input signal in real time. The interrelation of input signal and local PN code is shown as Fig. 6.

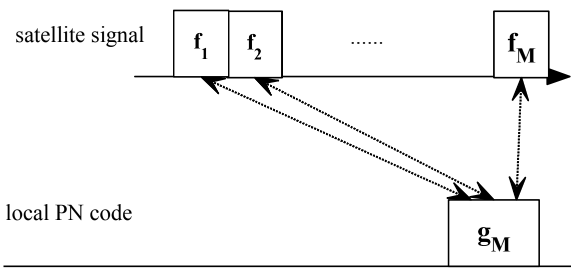

Fig. 6. Improved FFT direct acquisition algorithm architecture.

In a Doppler frequency unit, its algorithm flow is below:

Step 1. Receive the first segment input signal f_1, remove the carrier, and send it to cache after FFT.

Step 2. Set the last segment g_m of local PN sequence of the corresponding PRM module output time uncertainty spectrum, and send it to cache after FFT.

Step 3. Make conjugate multiplication of the two FFT results. Then conduct IFFT, setting the first half as the correlative value.

Step 4. If correlative peak value exceeds the threshold, it is taken as the sign that the signal is acquired.

Step 5. If no correlative peak value exceeds threshold, it is considered that in this part of time uncertainty no PN code matches input signal.

Step 6. Receive the next input signal, and send the FFT result to cache. Repeat Step 3-Step 5 till signal is acquired or the whole time uncertainty has been searched.

According to the former architecture to search PN code, every time MN time uncertainty spectrum is searched, M length-N signals should be zero-padded to $2N$ points to correlate with one length-2N local PN codes. Compared with local PN code glide FFT acquisition algorithm, it reduces computational complexity.

3.3. Improved PN Code Superposed FFT Acquisition Architecture

Known from the foregoing analyses, local PN code fixed FFT acquisition algorithm reduces computational complexity, compared with local PN code glide FFT acquisition algorithm, upon which, to further lower acquisition time, and improve the architecture. Set the last segment g_M of local PN sequence and middle segment $g_{M/2}$ of local PN code of the corresponding PRM module output time uncertainty spectrum, generating a new local PN code sequence l_M by superposing the two segments. Correlate it with received input signal in real time. The interrelation of input signal and local PN code is shown as Fig. 7.

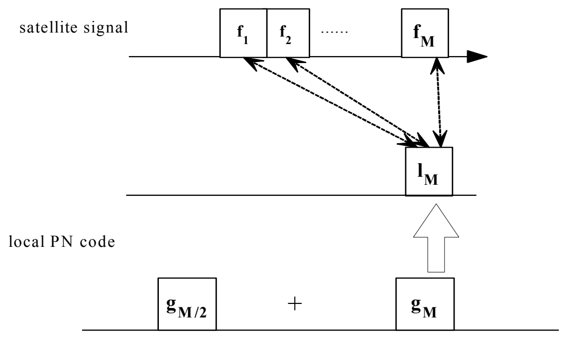

Fig. 7. FFT based PN code superposed direct acquisition algorithm architecture.

In a Doppler frequency unit, its algorithm flow is below:

Step 1. Receive the first segment input signal f_1, remove the carrier, and send it to cache after FFT.

Step 2. Set the last segment g_M of local PN sequence and middle segment $g_{M/2}$ of local PN code of the corresponding PRM module output time uncertainty spectrum. Superpose the two segments to generate a new PN code l_M.

Step 3. Send the FFT result of the new PN code l_M to cache.

Step 4. Make conjugate multiplication of the two FFT results. Then conduct IFFT, setting the first half as the correlative value.

Step 5. If correlative peak value exceeds the threshold, it is taken as the sign that the signal is acquired. Then calculate ambiguity.

Step 6. If no correlative peak value exceeds threshold, it is considered that in this part of time uncertainty no PN code matches input signal.

Step 7. Receive the second input signal f_2, and send the FFT result to cache. Repeat Step 4-Step 6 till signal is acquired or the whole time uncertainty has been searched.

The former flows are the superposition algorithm of two segments. If multiple-segment superposition algorithm is adopted, it needs simply to superpose multiple PN code segments in Step 2 to generate a new PN code segment. The improved PN code superposed FFT acquisition algorithm lowers average acquisition time compared with local PN code fixed FFT acquisition algorithm.

4. Analysis of Acquisition Time and Computational Complexity

Assuming the number of FFT unit process points is N, the number of points contained in the whole time uncertainty spectrum is MN, next will discuss resources and time that it takes up in one frequency unit to search the whole time uncertainty spectrum.

Learned from Fig. 6, local PN code glide FFT acquisition algorithm need to do 2 FFT and 1 IFFT, that is, in order to search the whole time uncertainty spectrum of MN, $2M$ FFT and M IFFT are needed. Learned from Fig. 7, in local PN code fixed FFT acquisition algorithm, input M segments require M FFT, but local PN code just do 1 FFT, that is, in the whole time uncertainty spectrum of MN, it needs $M+1$FFT and M IFFT. Learned from Fig. 8, in improved PN code superposed FFT acquisition algorithm, M segments input signals need M FFT, local PN code also needs 1FFT, that is, in the whole time uncertainty spectrum of MN, it needs $M+1$FFT and M IFFT.

If current received signal is $\{f_t\}$, $1 \le t \le M$ is guaranteed. Without loss of generality, assuming current received signal is uniformly distributed in the whole time uncertainty spectrum, i.e. its distribution probability is

$$P(t) = \frac{1}{M}, 1 \le t \le M \quad (1)$$

Assuming the time of processing N-point data be T_d, and time of sampling N-point data NT_s, with $T_d \le NT_s$ (when $T_d > NT_s$, acquisition is not in real time, which does not allow processes, thus parallel pipeline method is employed to guarantee the processes in real time), the time of processing N-point data is $T = NT_s$. For local PN glide FFT acquisition algorithm, the distributive relation of search time and current received signal is shown as Table 1.

Table 1. Acquisition time of local PN code gliding FFT acquisition algorithm.

t	1	2	…	M-1	M
Distribution probability	1/M	1/M	…	1/M	1/M
Acquisition time	T	2T	…	(M-1)T	MT

Average search time is

$$\begin{aligned} T_a &= \frac{1}{M}T + \frac{1}{M}2T + \cdots + \frac{1}{M}(M-1)T + \frac{1}{M}MT \\ &= (1+2+\cdots M)\frac{T}{M} \\ &= \frac{M(M+1)}{2} \times \frac{T}{M} \\ &= \frac{(M+1)T}{2} \end{aligned} \quad (2)$$

Similarly, received signal in the whole time uncertainty spectrum is presumed as uniformly distributed. And let receiver work in real time, process N-point data, with process time $T = NT_s$. Then when local PN code fixed FFT acquisition algorithm is exploited, search time and current receiving signal is shown as Table 2.

Table 2. Acquisition time of local PN code fixed FFT acquisition algorithm.

t	1	2	…	M-1	M
Distribution probability	1/M	1/M	…	1/M	1/M
Acquisition time	MT	(M-1)T	…	2T	T

Average search time is

$$\begin{aligned} T_a &= \frac{1}{M}MT + \frac{1}{M}(M-1)T + \cdots + \frac{1}{M}2T + \frac{1}{M}T \\ &= (M+M-1+\cdots+1)\frac{T}{M} \\ &= \frac{M(M+1)}{2} \times \frac{T}{M} \\ &= \frac{(M+1)T}{2} \end{aligned} \quad (3)$$

In the same processing condition, with superposed segments equal to K, for improved PN code superposed FFT acquisition algorithm, if not taking ambiguity calculation into account, the relation of search time and current received signal distribution can be shown as Table 3.

Table 3. Acquisition time of improved PN code superposed FFT acquisition algorithm.

t	1	…	M/K	…	M(K-1)/K+1	…	M
Distribution probability	1/M	…	1/M	…	1/M	…	1/M
Acquisition time	MT/K	…	T	…	MT/K	…	T

Average search time is

$$\begin{aligned} T_a &= (\frac{1}{M}T + \cdots \frac{1}{M}\cdot\frac{M}{K}T) + \cdots + (\frac{1}{M}T + \cdots \frac{1}{M}\cdot\frac{M}{K}T) \\ &= (1+2+\cdots\frac{M}{K})\frac{KT}{M} = \frac{\frac{M}{K}\times(\frac{M}{K}+1)}{2}\times\frac{KT}{M} \\ &= \frac{(M+K)T}{2K} \end{aligned} \quad (4)$$

The relation of input signal and local PN code is shown as Fig. 9. When $K \le [(M+1)/3]$ ($[(M+1)/3]$ denotes the maximum integer not greater than $(M+1)/3$), i.e. superposed local PN code segments are discontinued, shown as Fig. 8. If superposing sequences $\{g_1, g_4, g_7 \cdots\}$ with no overlaps between, then expression (4) is tenable; when $K > [(M+1)/3]$, some parts of signals of local superposed PN code are continuously superposed. According to former XFASR principle, its acquisition time is less than $(M+K)T/2K$. Due to impact of PN code cross correlation, correlative SNR is decreasing as K increases. Therefore to make receiver functions normally in relatively low SNR, K's value is usually less than $\mathrm{mod}(M+1,3)$.

The comparisons of the computational complexity and process time of the three algorithms is shown as Table 4.

Table 4. The comparisons of the computational complexity and process time of the three algorithms.

	PN code glide FFT acquisition algorithm	PN code fixed FFT acquisition algorithm	Improved PN code superposed FFT acquisition algorithm
Numberof times of FFT	2M	M+1	M+1
Numberof times of IFFT	M	M	M
Process time	(M+1)T/2	(M+1)T/2	(M+K)T/2K

Learned from the former table, PN code fixed FFT acquisition algorithm is the same with improved PN code superposed FFT acquisition algorithm in computational complexity, which is simpler than PN code glide FFT acquisition algorithm. Improved PN code superposed FFT acquisition algorithm's process time is less than that of PN code glide FFT acquisition algorithm and PN code fixed FFT acquisition algorithm.

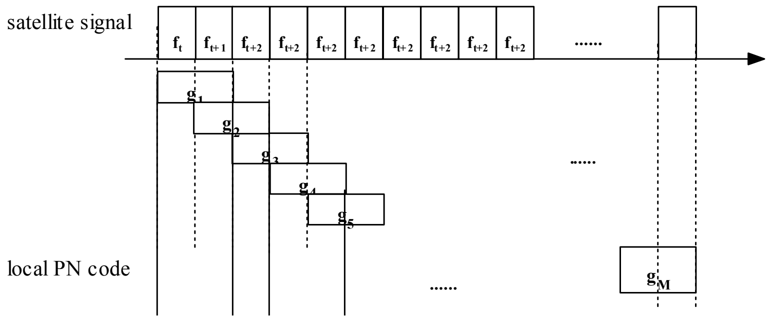

Fig. 8. The corresponding phase relationship of satellite signals and local PN code.

5. Conclusions

The paper analyzes common P code acquisition architecture, researches on FFT based direct acquisition algorithm of P code, and proposes an improved local PN code fixed FFT acquisition algorithm, simplifying computational complexity, upon which the algorithm architecture is further improved. Thus a PN code superposition based FFT acquisition architecture is put forward, shortening acquisition process time.

Acknowledgements

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