Research on Software Tracking Algorithm of Telemetry Spread Spectrum Signals

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Abstract. The stable and reliable tracking of the captured signal is the precondition for successfully demodulating the signal. Therefore, the realization of the tracking loop software processing becomes one of the key issues in the software processing of the spread spectrum signal. This paper analyzes the basic principles of PLL, code loop and carrier loop, and gives their software implementation methods, which lays a good foundation for the tracking of spread spectrum signals.

1. Introduction

The completion of the capture of the PN code phase and carrier frequency means that the PN code phase difference and the carrier frequency difference are controlled within a certain range, which is the "coarse synchronization" of the signal. This kind of coarse synchronization is far from enough to realize the function of spread spectrum measurement and control, and it also needs to track the loop to realize the accurate tracking signal changes of the local code phase, carrier frequency, and carrier phase as much as possible to keep the signal “precise synchronization”. This article mainly introduces the basic principle of the tracking algorithm, and gives a software implementation method.

2. Phase Locked Loop

Phase-locked loops are the basis for tracking loops. Delay-locked code tracking loop and Branch Costas are all phase-locked loops. In addition to different discriminators, the frequency-locked loop has the same structure as the phase-locked loop. All three can learn from the software of the phase-locked loop. Ring basic principles and software mathematical models are as follows.

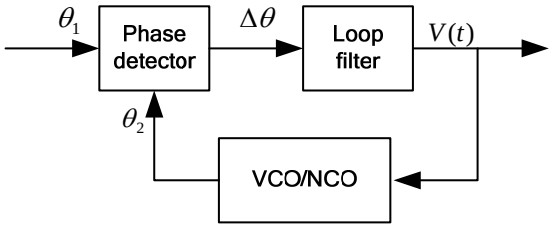


Figure 1. Phase lock loop basic block diagram

Figure 1 shows the basic block diagram of a phase-locked loop. The phase detector compares the input carrier phase with the local carrier phase estimate to obtain the phase estimation error. The error is filtered out by the loop filter and the output control corrects the local carrier.

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The design of analog phase-locked loops should take into account the effect of analog components such as capacitors and resistors in the circuit on the loop filter, and the design of digital phase-locked loops needs to take into account the effects of the number of signal quantization bits. For software phase-locked loops, without these additional considerations, the phase-locked loop design is simplified. The loop filter parameters affect the performance of the phase-locked loop. The smaller the loop bandwidth is, the higher the tracking accuracy is and the slower the tracking speed is; the higher the bandwidth is, the lower the tracking accuracy is and the faster the tracking speeds is. The flexibility of the software-enabled phase-locked loop is very high. A variable bandwidth strategy is adopted, and the loop filter parameters can be flexibly adjusted as needed. In the early stage of tracking, the larger bandwidth is used to increase the locking speed. In the latter stage of tracking, the bandwidth is reduced to improve the tracking accuracy.

3. Delay Lock Code Tracking Loop

In the process of receiving the spread spectrum signal, the accurate demodulation of the received signal must be performed under the condition that the local pseudo code and the received pseudo code phase are accurately synchronized, so that the correct modulation information and measurement information can be obtained. The role of the code tracking loop is to accurately track the phase change of the received pseudo code and keep the code phase error within a certain range. The basic principle of the code tracking loop is introduced below, and the software tracking method of the code tracking loop is given.

Because normally spread spectrum systems operate in a low signal-to-noise ratio environment, it is difficult to perform carrier tracking. The delay lock code tracking loop does not require the generation of the relevant carrier during the tracking process, so this paper uses a delay lock code to track the loop. The delay lock code tracking loop is mainly composed of an associated accumulator, a phase detector, a loop filter, and a code NCO.

The DDLL is generally composed of two related reception branches and one subtraction branch of advance and lag. The correction signal is obtained by subtracting the hysteresis branch and the advance branch, and the correction signal is used to control the local code phase so as to adjust the phase of the symbol. The software implementation of each part of the delay lock code tracking loop is given below.

Software code loops the phase correction method. The key to the software of the code tracking loop is the phase correction. The method of generating the local code in the software receiver is different from the hardware, which determines that the loop filter output has a different correction method for the local code phase. The generation process of the local code in the software receiver is to first generate a pseudo-code of the whole period according to the code pattern, and sample the generated pseudo code according to the relationship between the sampling frequency and the code rate. The generated pseudo-code after sampling is stored in an array form. In order to reduce the amount of computation, the pseudo-code data is not regenerated once it is generated. The periodicity of the pseudo code is used to correct the local code phase. The code phase correction principle is shown in Figure 2.

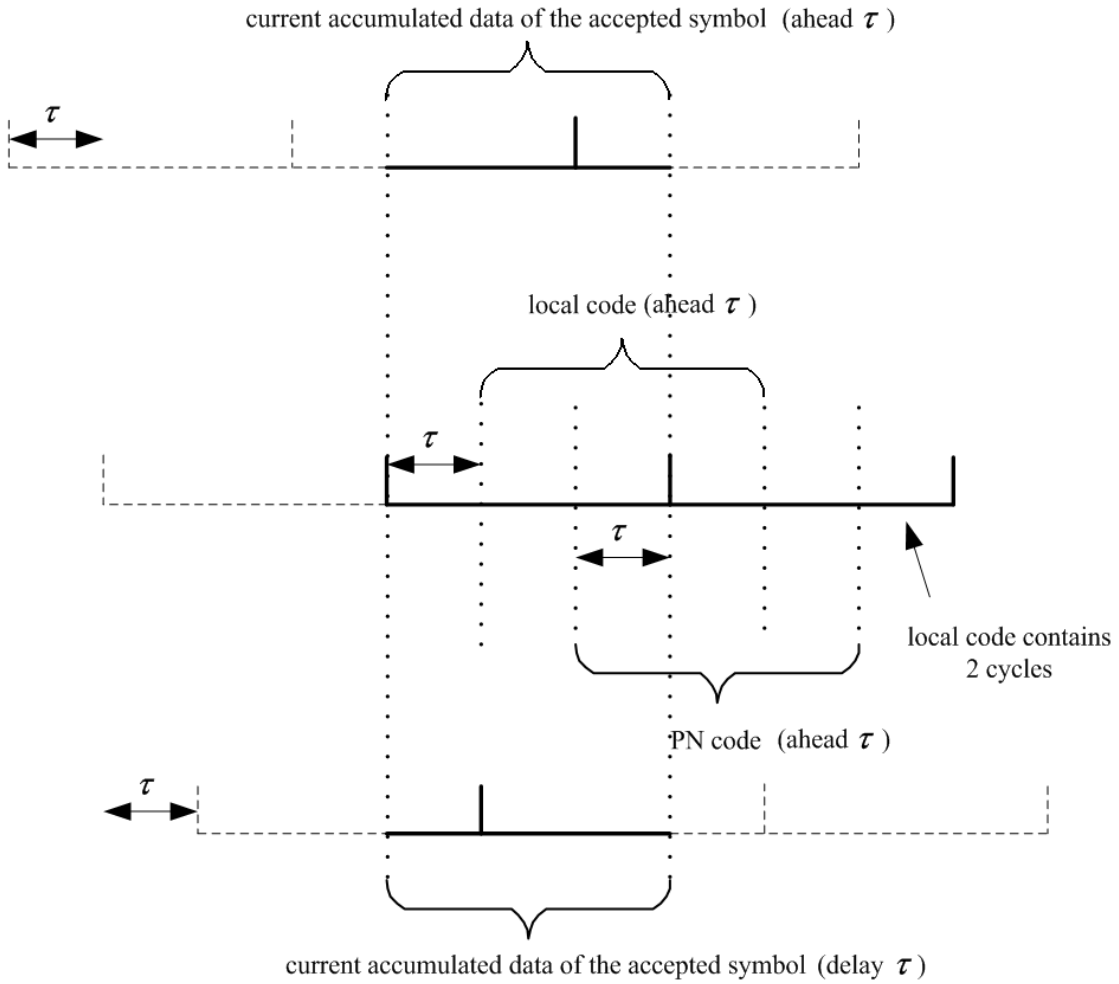


Figure 2. Local code phase correction principle

According to the existing derivation, the output of the loop filter is converted into a pseudo code phase difference:

$$\omega_n^2 \cdot T \cdot \sum_{k=1}^{n} V_c(kT) \tag{1}$$

To calculate the number of sampling points, it needsto move cyclically:

$$\Delta n = \omega_n^2 \cdot T \cdot \sum_{k=1}^{n} V_c(kT) / 2\pi \cdot f_s / f_{code} \tag{2}$$

This kind of software method uses the periodic nature of the pseudo code to eliminate the complicated implementation process of the code NCO, which also eliminates the time required to repeatedly generate the pseudo code. This is not achieved by the hardware implementation, and the general computer is fully utilized. Large storage capacity is the advantage. Since the phase delay accuracy is accurate to every sample point, the accuracy of this software design is also guaranteed. The simulation results prove the correctness of the design idea of the software code loop.

4. Software Carrier Composite Tracking Loop

After the successful acquisition of the received signal, the carrier frequency difference between the local carrier and the received signal is controlled within a certain range, but there are still residual frequency differences and phase differences, so that the carrier stripping cannot be fully realized, and the measurement and control data cannot be demodulated. This requires carrier tracking to further fine tune the carrier.

The carrier tracking loop has two kinds of phase-locked loops and frequency-locked loops. The PLL outputs the carrier phase difference control carrier NCO from the phase detector to complete carrier stripping. The FLL can estimate the center frequency of the carrier so that carrier detection is achieved. The ability of a PLL to tolerate noise is relatively good, but it does not interfere with the interference of the communication link. In particular, Doppler has a greater impact on detection. Dynamic stress causes the PLL to lose lock and the receiver will detect this with a sensitive phase-locked detector and return to the frequency-locked loop, and then repeat the lock-frequency loop closure process. This article adopts this kind of compound software to track the ring; its realization block diagram is shown as in Fig. 3. In the initial stage of carrier tracking, the frequency-locked loop is used for tracking. The loop tracking error is reduced to a certain range and transferred to the PLL tracking. The simulation results show that when the loop tracking error changes by ±5%, the loop transferred to the Costas loop can be locked directly in the new loop, and the tracking error does not overshoot.

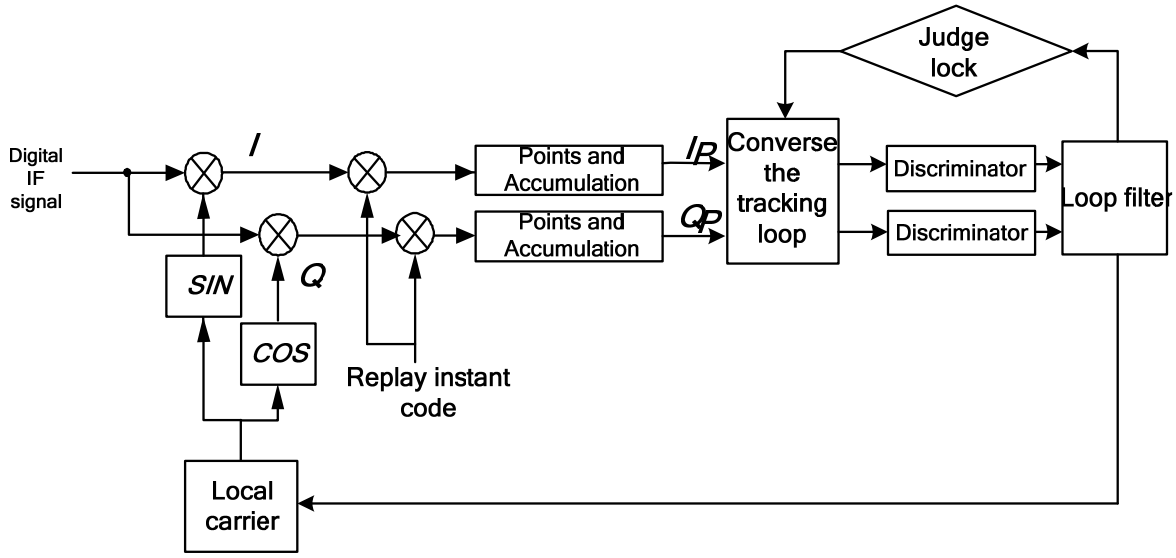


Figure 3. Composite Soft Ring Implementation Block Diagram

FLL is also called AFC. The main difference between a frequency locked loop and a phase locked loop is that the discriminator output is a frequency difference. The basic principle of the frequency locking ring is shown in Figure 4.

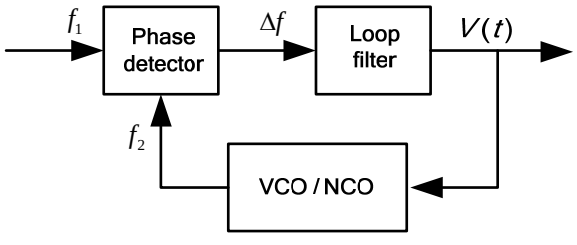


Figure 4. Frequency Locked Loop Principle

The output of the frequency-locked loop discriminator is proportional to the frequency difference of the carrier, so using the output of the FLL to control the NCO of the carrier can track the frequency. The composite soft-loop phase-locked loop uses Costats, also known as in-phase quadrature loops. This is because the measurement and control information of the modulation is retained when the received signal realizes the code stripping, which causes the signal phase to be reversed. The Costas Loop Software for Spread Spectrum Measurement and Control Signal Processing is shown in Figure 5.

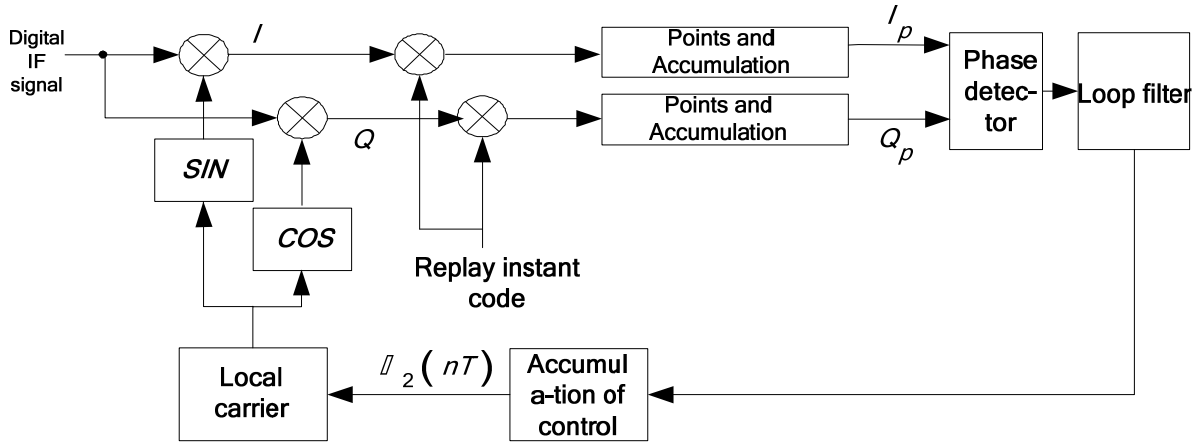


Figure 5. Costas Ring Software Block Diagram

The digital IF signal is digitally down converted by the digital to generate in-phase I and quadrature Q signals. The I and Q components are obtained by multiplying and multiplying the recurring instantaneous codes. The I and Q components pass through the phase detector and the loop filter, and the output carrier phase error control quantity corrects the local carrier. The task of the phase locked loop is to make the phase difference between the local carrier and the input signal zero, and any phase difference will be detected by the carrier tracking loop and corrected according to the size and direction.

When the traditional hardware implements the digital Costas loop, the output of the loop filter is the control of the local NCO. A variable-frequency sine and cosine signal is generated locally by looking up the table. The higher the NCO drive frequency, the longer the accumulator data width and the more accurate the phase adjustment. However, due to the hardware speed limit, the value cannot be taken too high. The software control of the Costas loop error control on the local carrier is completely different from the hardware implementation. The output of the loop filter is calculated by the relevant formula to obtain the total phase error of the local carrier and the received carrier, so that the local carrier can be corrected. The complicated process such as look-up table is omitted, and the accuracy of the adjustment is only the accuracy of the total phase error variable. If the variable is set to double, the phase adjustment accuracy can reach $1/2^{64}$ rad. The hardware accumulator is 32 bits, which can realize the highest NCO control accuracy of $\pi/4/2^{32}$ rad.

5. Summary

This paper mainly analyzes the basic principles of phase locked loop, delay locked code tracking loop and complex soft carrier tracking loop, and lays a good foundation for the tracking of spread spectrum signals.

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