Algorithm Theoretical Basis Document
SPS Baseband Processing

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1. INTRODUCTION

A navigation receiver must be able to acquire and demodulate the data transmitted from satellite to find the location of receiver. The generic navigation receiver block diagram in Figure 1-1 shows that signals from all the visible satellites are received at the antenna in the RF front end where received signals are down-converted to Intermediate Frequency (IF) and also converted from analog signal to the digital signal. The digitized IF signals are then passed to Digital Signal Processing (DSP) or **Baseband Processing** block of the receiver where measurements related to pseudo-range (Code Phase and Doppler) and demodulation of navigation data is carried out. The measurements and demodulated data are then passed on to the Navigation Processor where the final position calculation is done.

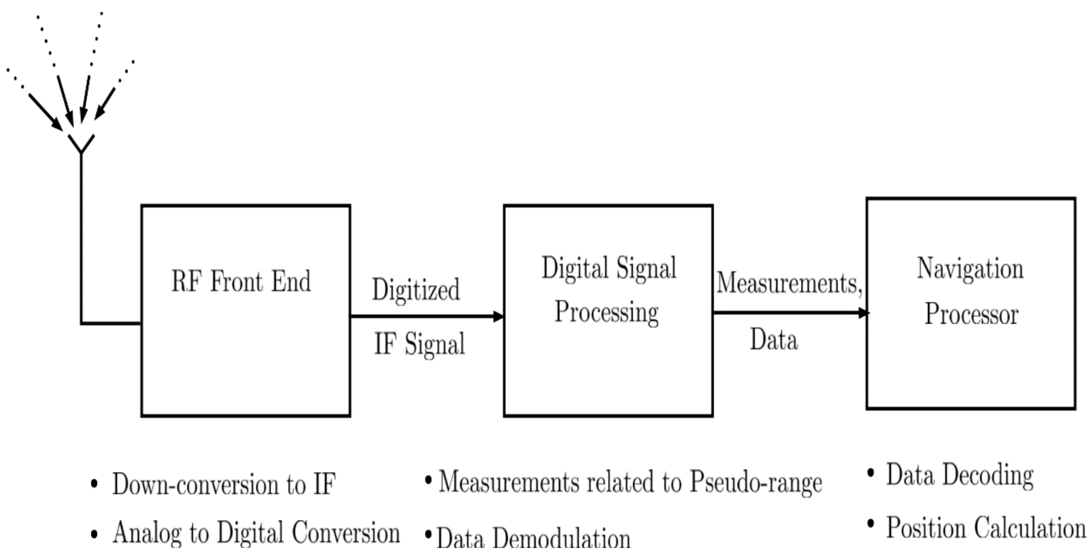

Figure 1-1 Generic Navigation Receiver Block Diagram

1.1.Product Overview

The product is MATLAB implementation of the Baseband Processing Block (DSP) of the navigation receiver. As described above the block takes the Digitized IF signal as the input, makes measurements (Code Phase and Doppler) and demodulates the navigation data present in the digitized IF signal. MATLAB is chosen as the platform for implementation due to its flexibility for modification and optimization of the parameters.

1.1.1.Product Description

A block diagram is shown below depicting the signal flow in the baseband processing.

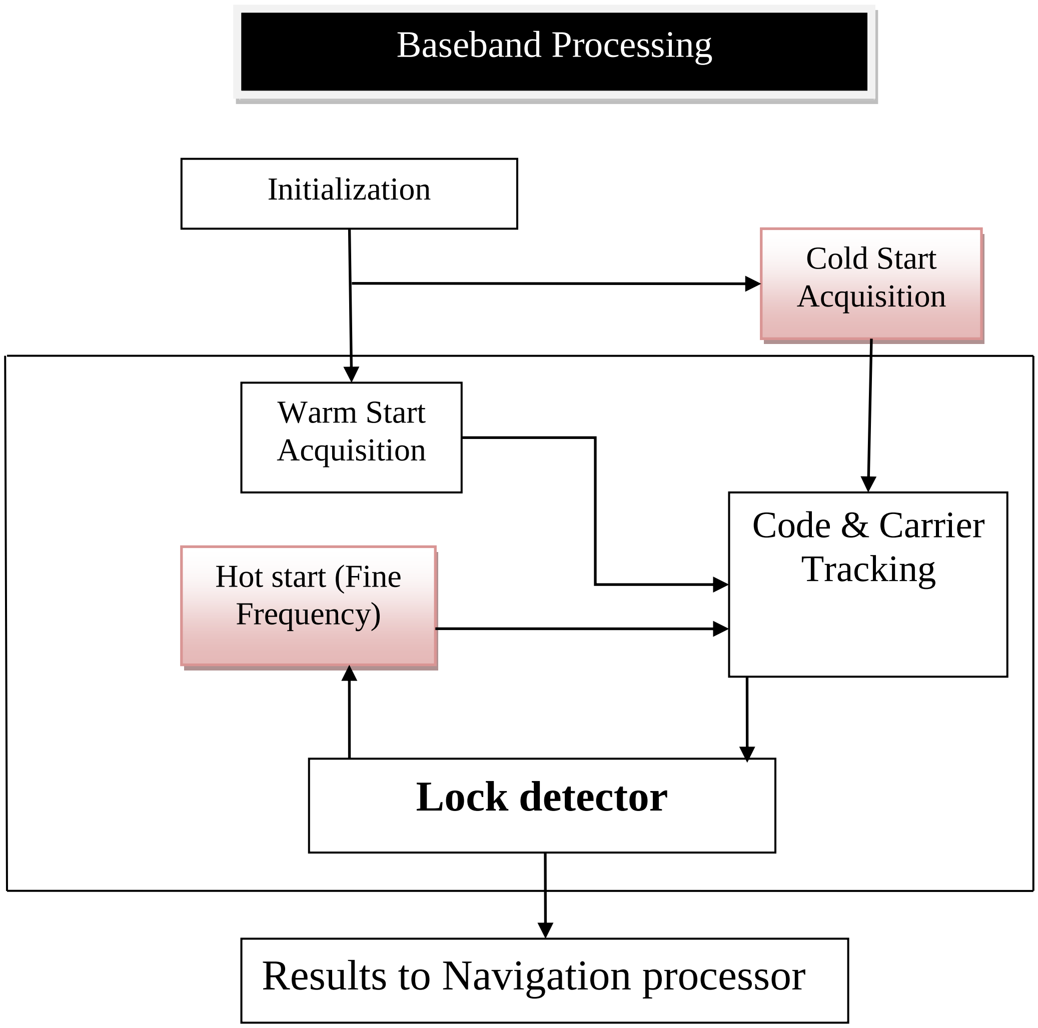

Figure 1-2 Description of Baseband Processing

The previously recorded or simulated digitized IF signal is read from a file in the Initialization part. Type of start (cold, warm or hot) is selected based on the availability of the previous measurements in the initialization. The Acquisition is performed accordingly. Right now, only two options are kept for start i.e. cold or warm start as it is assumed that previous estimates are either not available at all or only Doppler is known approximately. After acquisition, tracking is executed where each block of data is processed according to the measurements made during the processing of the previous block. The tracking results are passed on to the Lock Detector which checks for the propriety of the tracking and determine signal strength by approximately measuring the CNR (carrier to noise ratio). The decision on whether the lock sustains or there is requirement of a fine frequency search again (hot start) or there is no need to process for a particular satellite, is made by lock detector. The results are updated then and passed on to navigation processor.

1.1.2.Product Requirements

The Product (a MATLAB based Software Baseband Processor) requires settings to be made before starting the processing. Settings include signal properties (sampling frequency, IF frequency, data type, file location etc.) and system properties (selection of file reading parameters, acquisition and tracking parameter selection). A recorded or simulated signal digital IF file is the primary requirement.

2. ALGORITHM DESCRIPTION

A single channel of the baseband processor (which is called correlator receiver) is shown below. For the navigation processor to be able to calculate a position solution, demodulated data need to be supplied from the baseband processor. As the co-ordinates for at least four satellites are required, there can be a minimum of four channels in the baseband processor that can demodulate the data for the minimum required four satellites. In the implemented software receiver, the number of channels i.e. N is selectable in the initial settings.

The two essential measurements required for data demodulation are Code Phase and Doppler. These measurements are made in two stages. The first stage is acquisition where coarse estimates are calculated and the second is tracking where fine estimates are made. Each receiver channel where these two steps are carried out is called correlator receiver channel as shown in figure 2-1. Acquisition is a computationally demanding task. Therefore, instead of implementing individual acquisition block for each receiver channel, only one acquisition block is implemented which can be used by all the receiver channels on a shared basis.

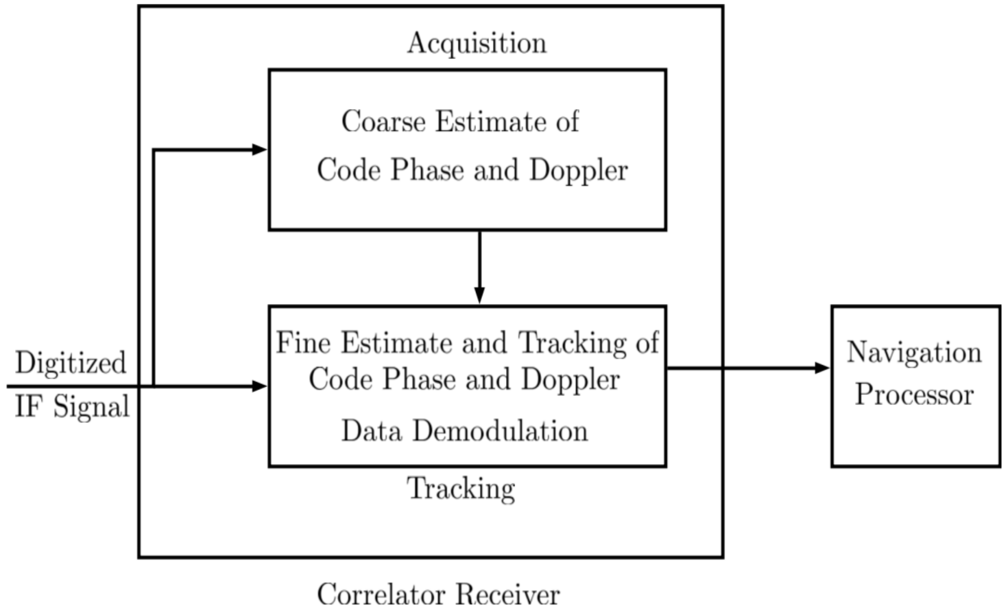

Figure 2-1: Correlator Receiver

2.1.Processing Outline

Along with Demodulated Data, Code Phase and Doppler estimates are also required for the pseudo-range calculation and further tracking of the signal. Also, as these estimates and navigation data are different for the different satellites, therefore for every satellite which is intended for processing, independent processing is required. Therefore, there are ‘N’ channels in baseband processing of the receiver. Where, ‘N’ is equal to number of satellites the receiver designer intends to process, as shown in figure 2-2.

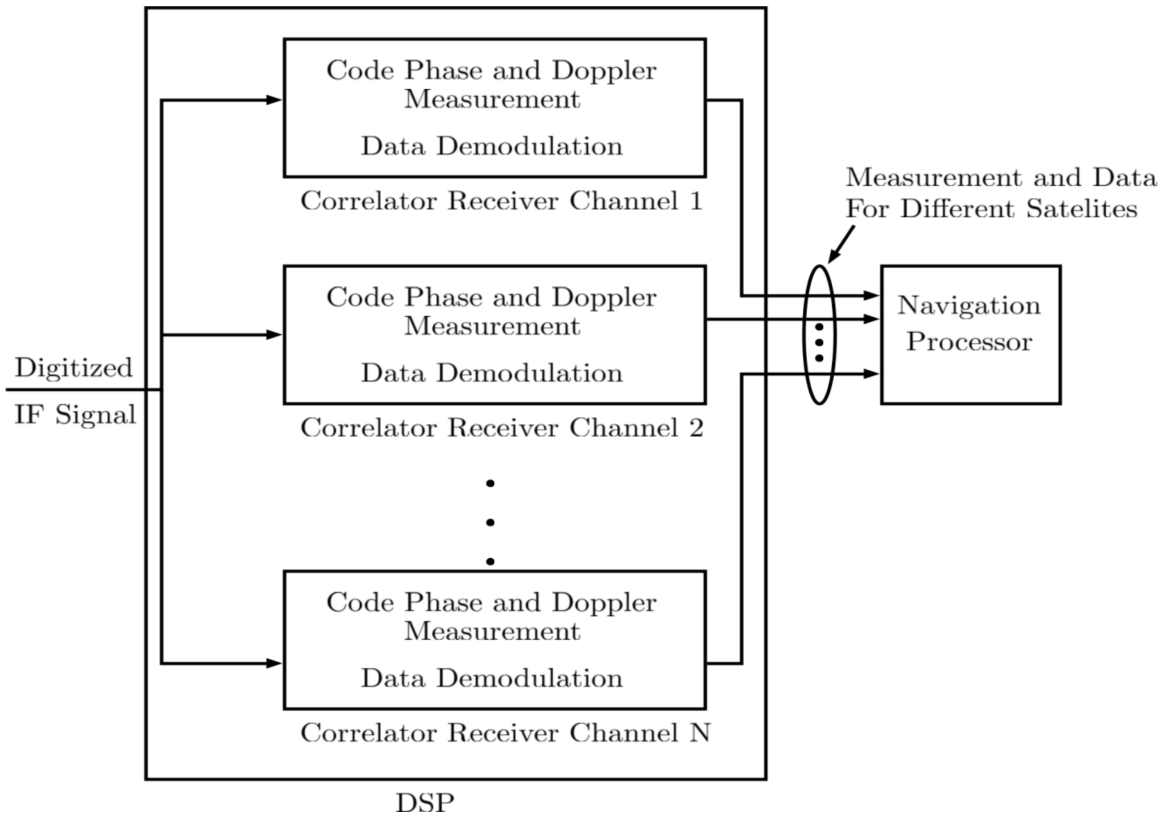

Figure 2-2 Baseband Processing Outline

2.2. Algorithm Input

The input required is the digital signal obtained from RF front End, down-converted to IF. The Satellite Signal Structure for Standard Positioning Service (SPS) is effectively the multiplication of the bipolar navigation data bits, bipolar PRN code chips and a high frequency carrier as shown in figure 2-3. Data rate for navigation data bits is 50 sps (1/2 rate FEC encoded), that makes time length of a single data bit equal to 20 ms. Chip rate for PRN code is 1.023 Mcps, as code length is 1023 chips, time length of a code is 1ms. There are 20 full length codes in a single navigation data bit.

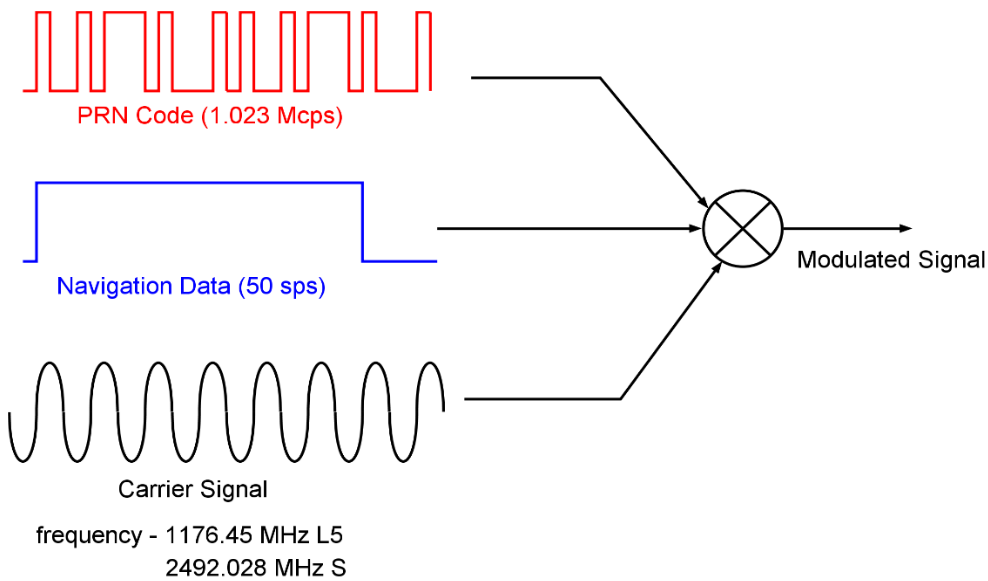

Figure 2-3: Signal Structure

IRNSS SPS signals are transmitted at two carrier frequencies, one in L-Band and other in S-Band. In L-Band, L5 frequency i.e. 1176.45 MHz is used as carrier while in S-Band, 2492.028 MHz is used. Each chip transmitted at L5 modulates 1150 cycles of the carrier (1150×1.023 MHz = 1176.45 MHz) and each chip at S-frequency modulates 2436 cycles of the carrier (2436×1.023 MHz = 2492.028 MHz). The BPSK modulated signal is transmitted from the satellites which is received and processed at the receiver.

2.3.Theoretical Description

The Acquisition and tracking of received IF signal is done, here the process of Correlation is used for calculating the code phase of the signal. Correlation between two signals is calculated by sample to sample multiplication and accumulation. The PRN codes used in navigation signals are Gold Codes (due to their good auto-correlation and cross-correlation properties). The PRN replica generated at the receiver is correlated with the received carrier wiped-off signal. A general example of a PRN code and its correlation properties is shown in figure 2-4, the replica is generated with different code phase shifts at the receiver, whenever the code phase of the generated replica and that of the incoming carrier wiped-off signal match, correlation results in a high value (in the figure correlation value at correct phase is ‘1’) which is otherwise a very low value (in figure the correlation at incorrect code phase values is '-1/number of chips in the code'). This concept is used for estimating the code phase.

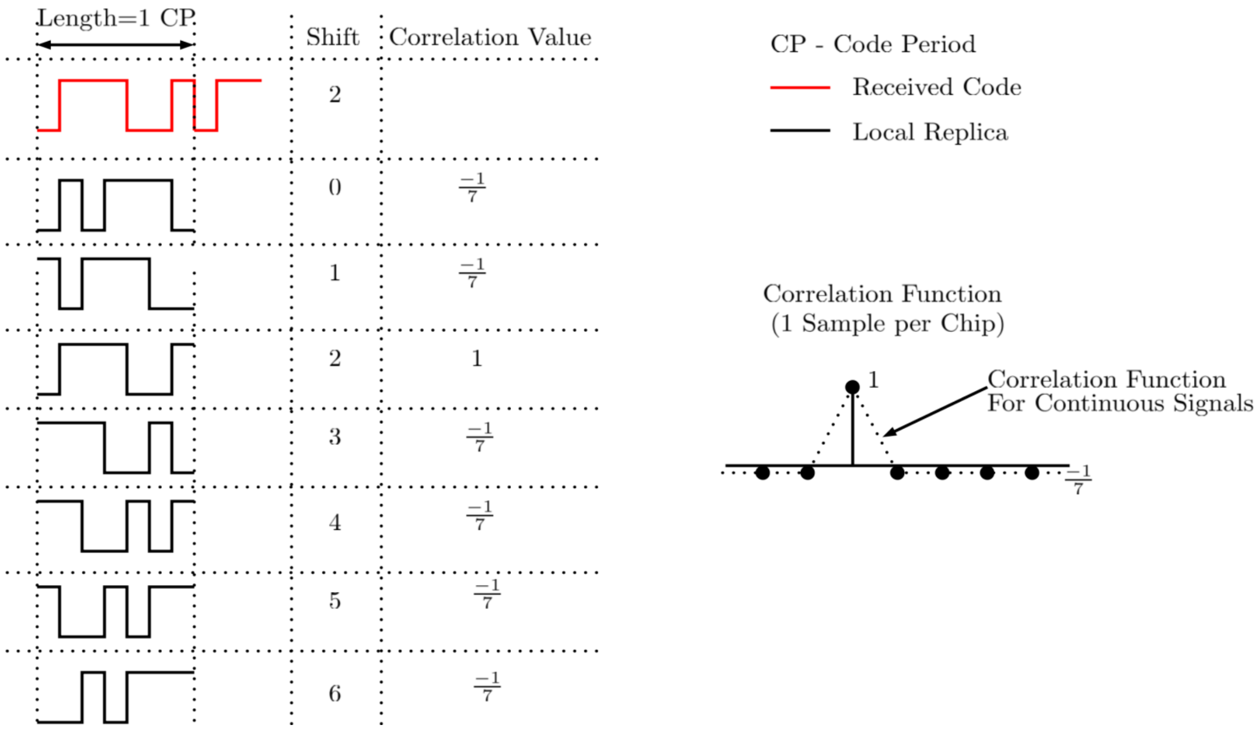

Figure 2-4: The Process of Correlation

Signal Acquisition:

Acquisition is the two dimensional search for code phase and Doppler for the intended PRN code. A grid of correlation values, taking the frequencies around IF (in the range of Doppler, generally ± 10 KHz) on one axis and the possible values of code phase on the other axis is calculated. The peak values in the grid are taken for making a decision on whether the satellite for which the search is going on is present or not. There are several approaches for acquisition, the approach used in this product is **serial code phase and serial frequency search.**

In this approach, each code phase shift is searched (correlation is calculated for each phase shift) at every frequency bin as shown in figure 2-6. Frequency bins around IF are separated with a size step, code phase step can be between 1 chip to a fraction of chip (smallest fraction = 1/number of samples in a chip). Taking the computational complexity and accuracy in to account, generally it is chosen as half chip (2 samples per chip). The frequency step size chosen is 500 Hz, ensuring the orthogonality among the different locally generated carriers.

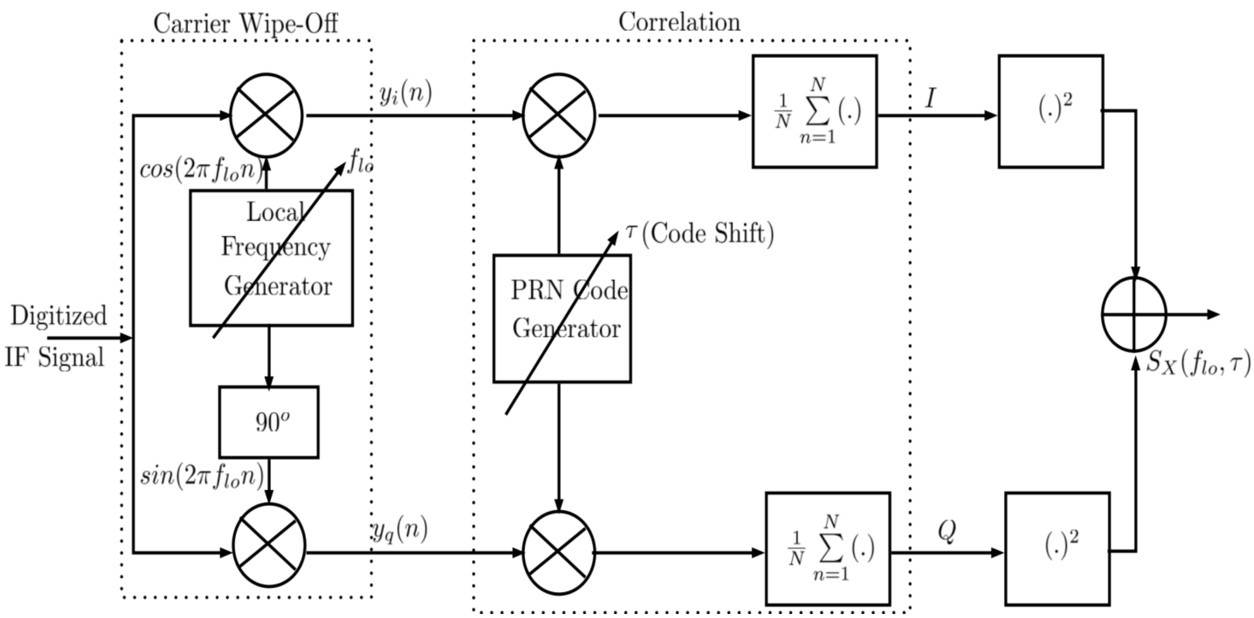

Figure 2-5 Serial code phase and serial frequency search

The function of acquisition process is to reduce the ambiguity region in code phase and frequency domain. The initial ambiguity in code phase is equal to the period of the PRN code (1 ms in case of IRNSS SPS) as the signal reception can start at any code phase. The initial ambiguity in frequency in is taken as ±10 KHz around IF (Making a total of 20 KHz) taking in the account the Doppler due to relative motion between satellite and receiver. As can be seen from figure 2-6, this ambiguity region is reduced to one frequency step (500 Hz) and one code phase step (some samples less than total number of samples in a chip).

The grid values are calculated serially in code phase and frequency domain according to the process shown in figure 2-5. Then this grid is analyzed for the decision if the satellite is present or not. The maximum value (the first peak) in the grid is taken as signal power estimate. A second peak, which is found after removing the first peak and values around it (to ensure that correlation contribution is close to zero), is taken as noise power estimate. The ratio of first peak to second peak is compared with pre-defined acquisition threshold, if it crosses the threshold satellite is declared to be present and if it does not, then it is concluded that satellite is not present. Therefore, selection of acquisition threshold is very critical in avoiding false alarms and ensuring the detection of visible satellites.

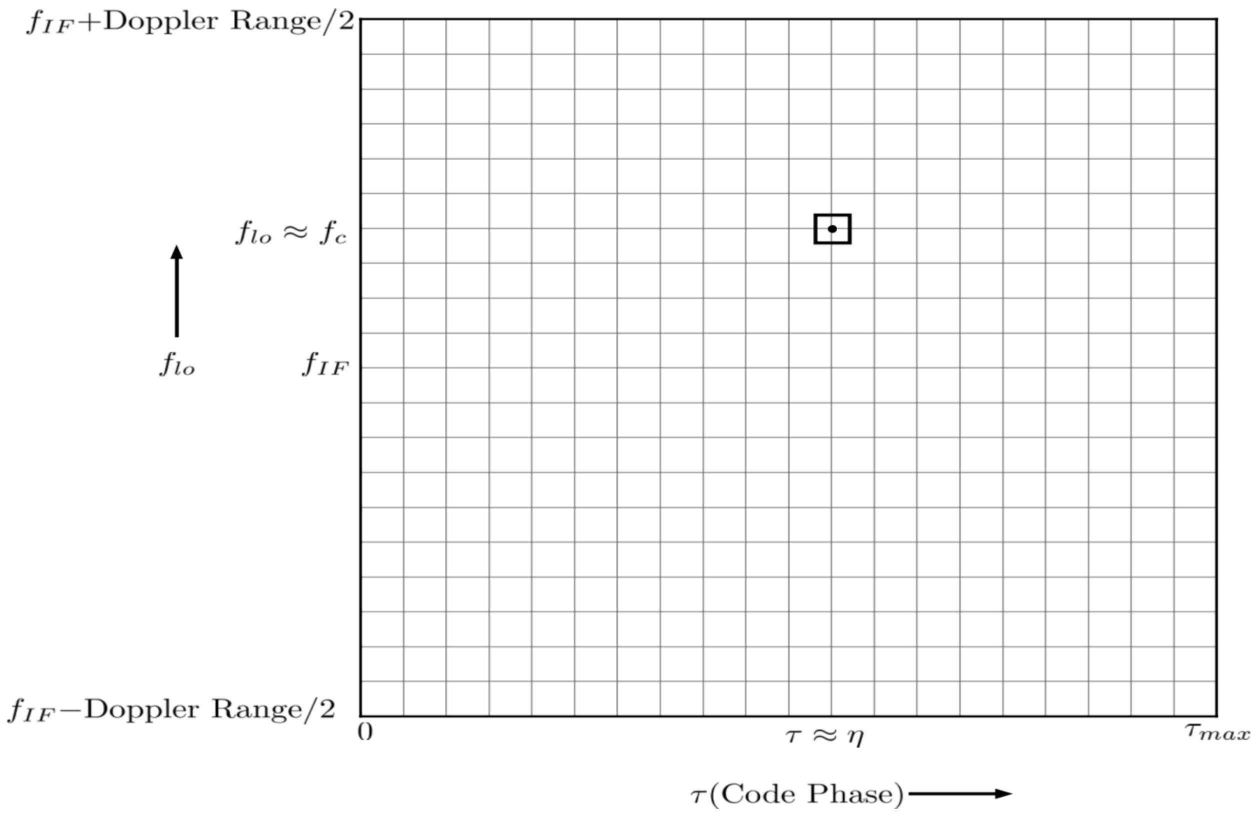

Figure 2-6 Acquisition Grid

Signal Tracking:

Tracking serves two purposes, one is converting the coarse estimates in to fine estimates and other is continuously keeping track of the incoming code phase, carrier phase and Doppler frequency. A block diagram for tracking is shown in figure 2-7. There are two loops, code tracking and carrier tracking. Code tracking loop estimates and tracks the code phase, while the carrier loop estimates and tracks the carrier frequency and carrier phase.

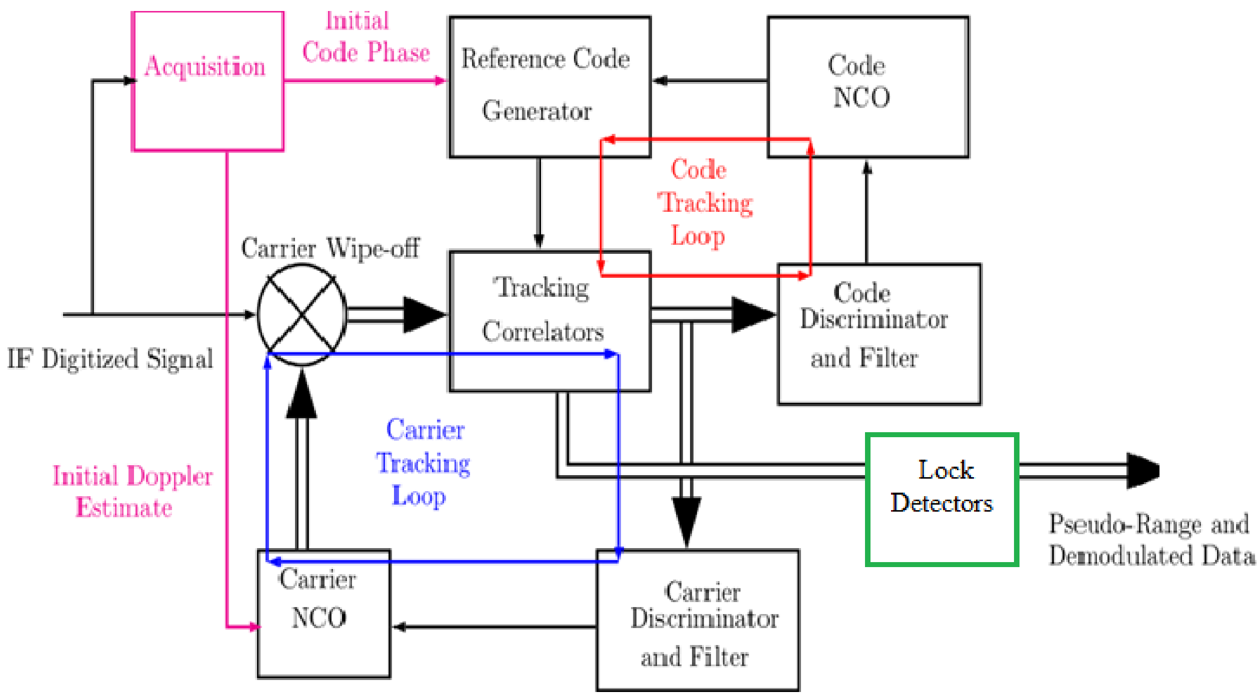

Figure 2-7 Block Diagram for Tracking

Carrier tracking Loop:

Operation of carrier tracking loop: The Carrier (in-phase and quadrature) is generated at the carrier NCO which is used for carrier wipe-off as shown in figure 2-8. Carrier wiped-off signal is correlated with the reference or replica code for calculating the correlation values. These values are then used by phase and frequency discriminators to calculate the phase deviation and frequency deviation between the incoming signal and carrier generated at the NCO. Next, these measurements are smoothened using loop filters and then NCO is updated with smoothed phase and frequency. Thus, a carrier loop can be a Phase Locked Loop (PLL) or Frequency Locked Loop (FLL) or hybrid containing both, PLL and FLL.

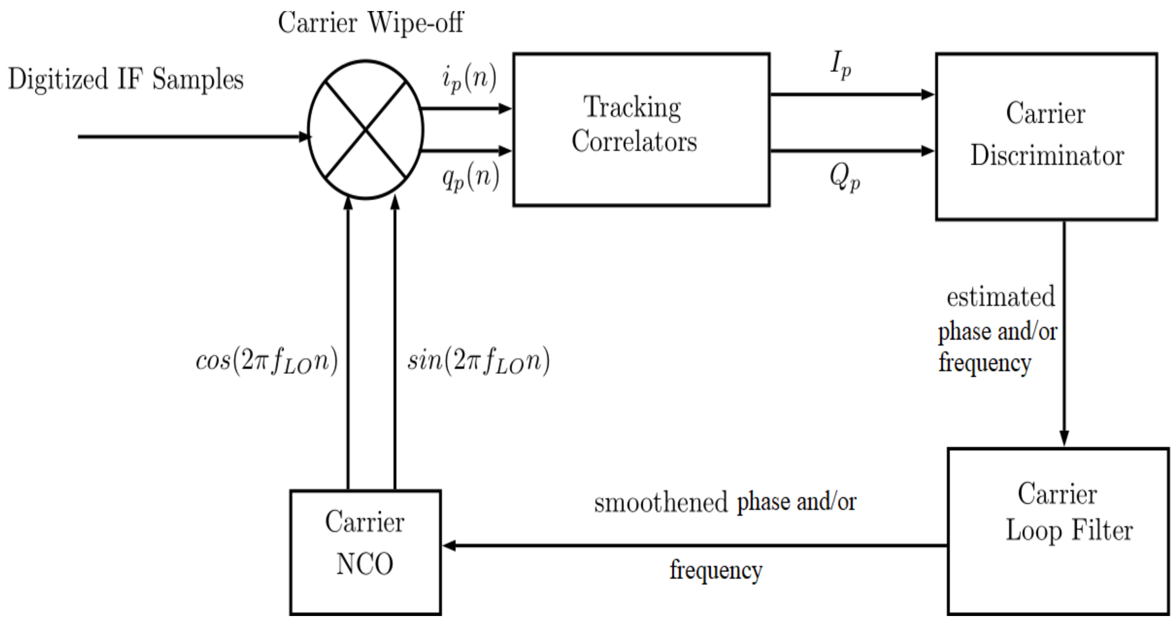

Figure 2-8 Carrier Tracking Loop

Code Tracking Loop:

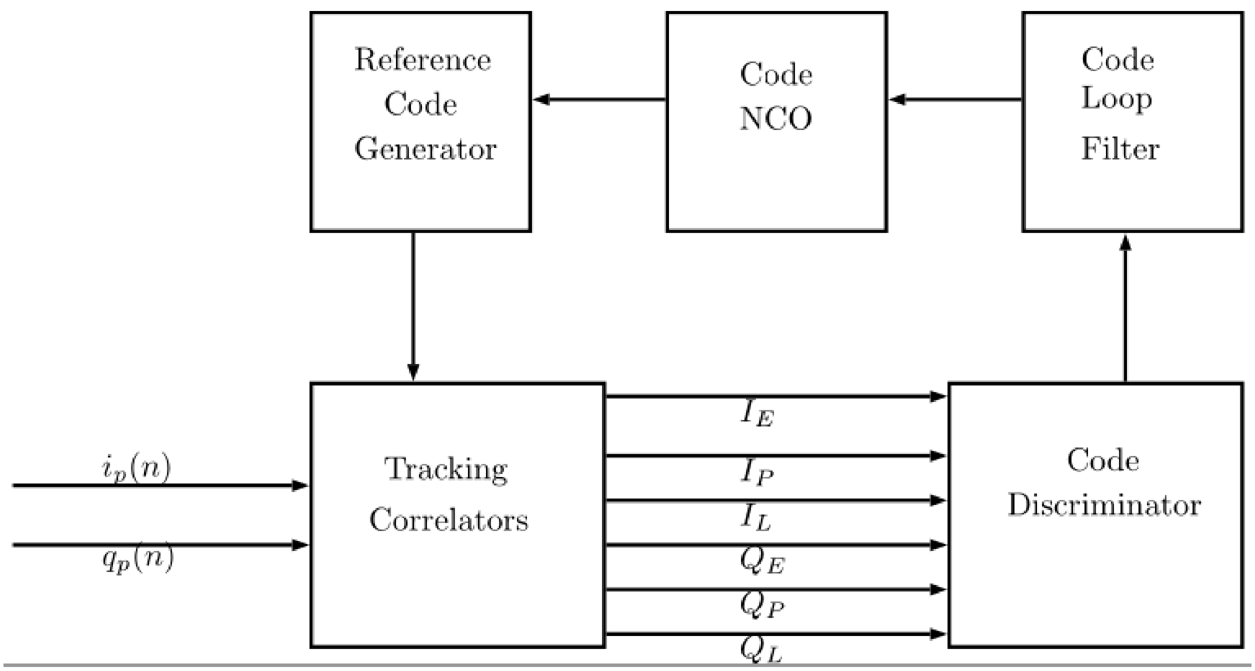

Figure 2-9 Code Tracking Loop

Code phase is tracked using three reference codes named Early, Prompt and Late codes. Early and late codes are half chip shifted versions (in either direction) of the prompt in standard receivers. The correlation values are used for finding out the direction in which the codes need to shift to track the code phase.

The discriminator calculates the difference between Early and Late envelop, to determine the direction of shift which will lead to the correct code phase as shown in figure 2-10.

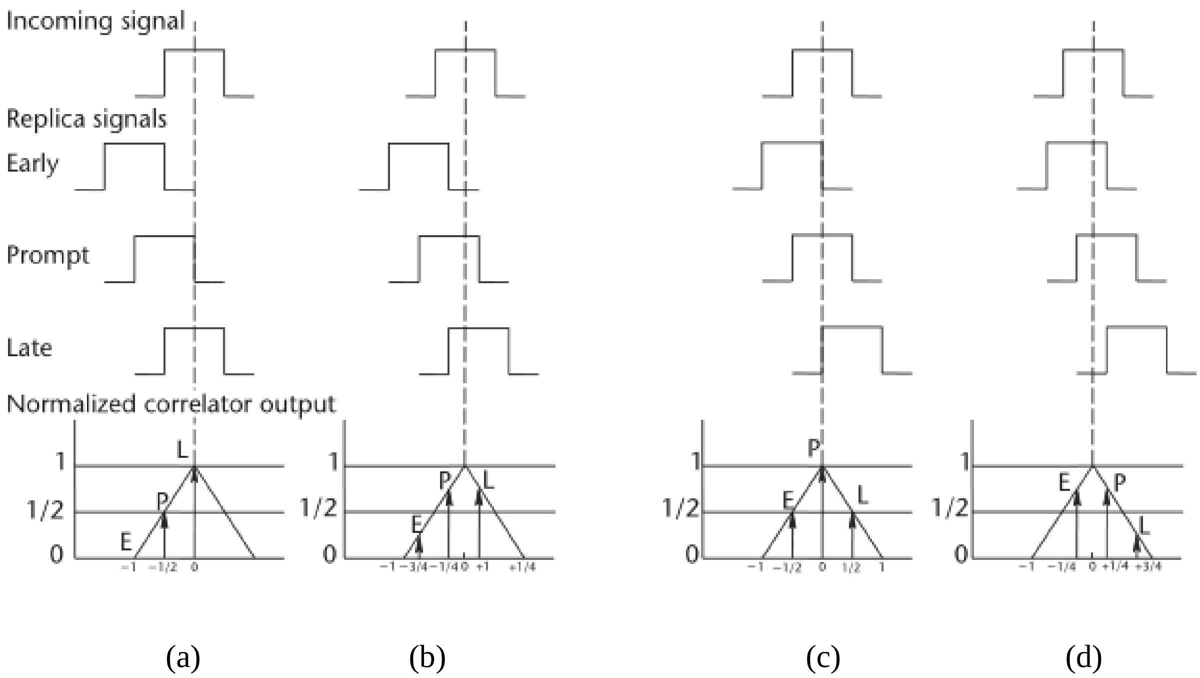

Figure 2-10: Code correlation Phases: (a) replica code ½ chip early,(b) replica code ¼ chip early, (c) replica code align, (d) replica code ¼ chip late.

As can be seen from figure here,

If $E - L > 0$ Shift in Left

Else $E - L < 0$ Shift in Right

When $E - L \approx 0$ Code Phase is correct

Here E, P and L are early, prompt and late envelopes.

The code phase values thus obtained are smoothened using the loop filter and used in pseudo-range calculation.

Lock Detectors:

Lock detector is necessary to ensure the lock conditions, whether phase and frequency loops are working within acceptable limits or not. Also, the signal strength (C/N) measurements are made to ensure the reliability of demodulated data. Whenever a lock fail condition occurs according to C/N or phase/frequency deviations, lock detectors determines the acquisition status i.e. if the fine frequency search (hot start) is required or signal strength is low enough to drop the signal for the further processing.

When lock sustains, navigation data demodulation and delta pseudo-range measurements are made.

Demodulation of Navigation Data:

Once the fine estimates of code phase and carrier frequency and phase are obtained in acceptable limits which are determined by lock detectors, the one of the component I_P orQ_P(depending on the algorithm design) is used for data demodulation. In this product $Q_P$is used as data component. First the transition boundaries are determined by looking for a sign change. Then the values of Q_P for a full data bit, starting from a data boundary, are averaged to determine whether the bit is '1' or '0'. Lock detectors are essential for successful data demodulation. Lock detector calculates the value of received CNR and compare it with a threshold. Also, it watches out whether there are sign transitions in between the estimated data bit boundaries. Once these criteria are satisfied, lock is declared to be obtained and data demodulation starts.

Delta Pseudo-range:

Delta pseudo-range is the time elapsed between the start of the reception of the signal and the first navigation data bit boundary. It is determined, only when the lock is obtained, by measuring the time between the start of reception and first data boundary thereafter.

2.3.1.Physical Description

To Be Determined (TBD)

2.3.2.Mathematical Description

As shown in figure 1-1, Assuming, $d(t)$ is the data bit transmitted from satellite, $p(t)$ is the PRN code transmitted from the satellite and $c(t)$ is the Carrier signal transmitted from satellite.

The time duration of data-bit and PRN chip is 20ms and 0.9775μs respectively.

The IRNSS satellites transmit the carrier frequency in L5 band and S-band, the expression for data, PRN code and Carrier is defined as

$$d(t) = \sum_{i=-\infty}^{\infty} d(i) rect\left[t - \frac{T_d}{2}\right] \quad (1)$$

Where T_d is data bit time of 20ms.

$$p(t) = \sum_{i=-\infty}^{\infty} p(i) rect\left[t - \frac{T_c}{2}\right] \quad (2)$$

Where T_c is time of one chip i.e 1/1.023Mcps or 0.9775µs.

$$c(t) = cos2\pi f_c(t) \quad (3)$$

The carrier frequency f_c for L5 band is 1176.45MHz and for S-band is 2492.028MHz.

This signal transmitted from satellite can be expressed as

$$x_t(t) = d(t)p(t)\cos(2\pi f_c t) \quad (4)$$

When this signal is received at the antenna of receiver the signal is

$$y(t) = \sqrt{P} d_{T_d'}(t - t_0) p_{T_{chip}'}(t - t_0) cos2\pi f_c'(t - t_0) \quad (5)$$

Where,

$d_{T_d'}$is data bits received with bit periodT_d'

$p_{T_{chip}'}$is chip bit received with chip durationT_{chip}'

$t_0$is the travel time of signal from satellite to receiver,

$\sqrt{P}$is Power of received signal,

$f_c' = f_c + f_d$,

$f_d$is Doppler frequency.

Once this signal $y(t)$ is received at the RF front end here the signal is down converted and it is represented as

$$y_d(t) = \sqrt{P} d_{T_d'}(t - t_0) p_{T_{chip}'}(t - t_0)\cos(2\pi f_c'(t - t_0)) * \cos(2\pi(f_c - f_{IF})t) \quad (6)$$

$$y_d(t) = \frac{\sqrt{P} d_{T_d'}(t-t_0) p_{T_{chip}'}(t-t_0)}{2} [\cos[(2\pi(f_c' + f_c - f_{IF})t - 2\pi f_c' t_0)] + \cos[(2\pi(f_c' - f_c + f_{IF})t - 2\pi f_c' t_0)]] \quad (7)$$

Substituting $f_c' = f_c + f_d$, *and phase in signal* $\theta_0 = -2\pi f_c' t_0$

$$y_d(t) = \sqrt{P} \frac{d_{T_d'}(t-t_0) p_{T_{chip}'}(t-t_0)}{2} [\cos(2\pi(2f_c + f_d + f_{IF})t + \theta_0) + \cos(2\pi(f_d + f_{IF})t + \theta_0)] \quad (8)$$

High frequency component is ignored due to filtering effects in the RF front end the $y_d(t)$ can be written as

$$y_d(t) = \sqrt{P}\,\frac{d_{T_d'}(t-t_0)p_{T_{chip}'}(t-t_0)}{2}\,[\cos(2\pi(f_d + f_{IF})\,t + \theta_0)] \qquad (9)$$

This signal $y_d(t)$ is converted to digital form using analog to digital convertor in RF front end is given by

$$y_d[n] = \sqrt{P}d_{T_d'}([nT_s - t_0])p_{T_{chip}'}([nT_s - t_0])\cos(2\pi((f_{IF} + f_d)nT_s) + \theta_0) \qquad (10)$$

T_s is the sampling time depending upon the selected sampling frequency.

For the simplification of the expression $\sqrt{P}$ and T_s has been removed from the expression and now the expression can be written as

$$y_d[n] = d_{T_d'}[n - t_0\,]p_{T_{chip}'}[n - t_0\,]\cos(2\pi(f_{IF} + f_d\,)n + \theta_0) \qquad (11)$$

Where, θ_0 is phase introduced in the carrier.

Now from figure 2-5 the carrier wiped-off in phase and quadrature components are

$$y_i[n] = y_d[n](\cos(2\pi f_{lo} n)) \qquad (12)$$

$$y_q[n] = y_d[n](\sin(2\pi f_{lo} n)) \qquad (13)$$

$$I = \frac{1}{N}\sum_{n=1}^{N} y_i[n]\,C_{rep}(n - \tau) \qquad (14)$$

$$Q = \frac{1}{N}\sum_{n=1}^{N} y_q[n]\,C_{rep}(n - \tau) \qquad (15)$$

Where, $C_{rep}(n - \tau)$is the replica code generated at the receiver.

$$S\chi(f_{lo}, \tau) = I^2 + Q^2 \qquad (16)$$

When $n_0 \approx \tau$, we get maximum correlation in the grid.

Using ratio of first peak and second peak and acquisition threshold, signal acquisition decision is made. Once the signal is acquired the coarse estimates are passed on to tracking as shown in figure 2-7.

Assuming initial Code Phase as τ_{in} and initial Carrier Frequency (Doppler estimate) as f_{in}, the signal received from carrier Numerical Controlled Oscillator (NCO) assuming initial phase of the signal is zero (i.e. $\theta_0 = 0$) is

$$y_I = \cos(2\pi f_{in} n) \qquad (17)$$

$y_Q = \sin(2\pi f_{in} n)$ (18)

Carrier Discriminator is used to estimate phase and frequency using PLL and FLL.The discriminator (figure 2-9) used in case of PLL is

$\theta = \tan^{-1}(\frac{I_P}{Q_P})$ (19)

Where, θ is the estimated phase by phase discriminator.

In case of FLL, the estimated frequency deviation is calculated as

$\Delta f = (\theta_2 - \theta_1)/(2\pi T_{\{loop\}})$ (20)

Where, $(\theta_2 - \theta_1)$ is the difference between current and previous phase deviation estimates and $T_{\{loop\}}$ is loop update time.

Note: The loop update time is equal to two code periods i.e. 2ms. As two phase estimates are required for frequency deviation estimation, the phase which is calculated every code period (1ms) cannot be updated to NCO every 1ms in order to have a correct estimate of frequency estimate.

The phase deviation and frequency deviation estimates from the discriminators are fed to the loop filter which is used to smoothen the incoming phase and frequency

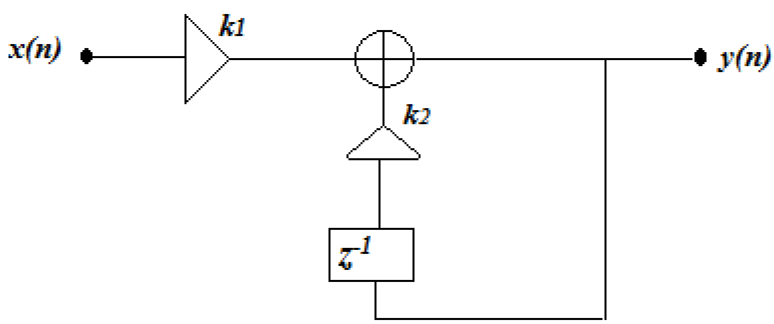

Figure 2-11 First order loop filter

The time domain equation for a general first order loop is given below:

$$y(n) = k_2 y(n-1) + k_1 x(n) \quad (21)$$

Where $y(n)$ is output and $x(n)$ is input of the loop filter, k_1 and k_2 are the filter coefficients that determine the noise bandwidth and response time of the filter. A careful choice is required for the coefficients k_1 and k_2 .

When the phase is given at input of loop filter we obtain the smoothen phase as ${\theta_0}'$ and similarly for smoothen frequency is $\Delta f'$. The smoothened phase and frequency deviations are applied to carrier NCO.

$$y_I = \cos((2\pi f_{in} + \Delta f')n + \theta_0') \quad (22)$$

$$y_Q = \sin((2\pi f_{in} + \Delta f')n + \theta_0') \quad (23)$$

And this process continues until receiver stops.

For Code Tracking, the outputs of tracking correlators calculated using Early, Prompt and Late codes are used.

For the first time after acquisition, Prompt code is generated as$C_{rep}(n - \tau_{in})$ using the initial code phase estimate. The prompt correlator outputs are given as (as per figure 2-9):

$$I_p = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\cos(2\pi f_{in} n) C_{rep}(n - \tau_{in}) \quad (24)$$

$$Q_p = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\sin(2\pi f_{in} n) C_{rep}(n - \tau_{in}) \quad (25)$$

Where $C_{rep}(n - \tau_{in})$ replica code generated at the receiver

As Early and Late codes are half chip shifted versions of Prompt code, they are generated by shifting the prompt code in either direction. For Early replica code generated as $C_{rep}(n - \tau_{in} - \frac{el}{2})$ and Late, replica the code generated as $C_{rep}(n - \tau_{in} + \frac{el}{2})$. el is the spacing between early and late codes which is kept equal to 1 chip.

The expression for Early and Late correlation values can be written as:

$$I_E = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\cos(2\pi f_{in} n) C_{rep}\left(n - \tau_{in} - \frac{el}{2}\right) \quad (26)$$

$$I_L = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\cos(2\pi f_{in} n) C_{rep}\left(n - \tau_{in} + \frac{el}{2}\right) \quad (27)$$

$$Q_E = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\sin(2\pi f_{in} n) C_{rep}\left(n - \tau_{in} - \frac{el}{2}\right) \quad (28)$$

$$Q_L = \frac{1}{N}\sum_{n=1}^{N} y_d[n]\sin(2\pi f_{in} n) C_{rep}\left(n - \tau_{in} + \frac{el}{2}\right) \quad (29)$$

The envelope values are calculated from the correlation values as given below:

$$E = \sqrt{}(I_E^2 + Q_E^2) \quad (30)$$

$$P = \sqrt{}(I_P^2 + Q_P^2) \quad (31)$$

$$L = \sqrt{}(I_L^2 + Q_L^2) \quad (32)$$

As it can be seen from figure 2-10,

If $E - L > 0$ Shift in Left i.e. $\tau_{in} \leftarrow (\tau_{in} - 1)$

Else $E - L < 0$ Shift in Right i.e. $\tau_{in} \leftarrow (\tau_{in} + 1)$

When $E - L \approx 0$ Code Phase is correct and no sifting required.

2.4.Algorithm Output

The algorithm outputs are:

1. Demodulated data: Updated every bit duration (20 ms) for the channels in which lock sustains.
2. Code phase estimate: Filtered code phase updated every bit duration (20 ms) for every channel.
3. Doppler (carrier frequency) and carrier phase: Estimated every 1ms can be given at any rate less than or equal to 1 KHz for every channel
4. Pseudo-range: Updated whenever data transition occurs for the channels in which lock sustains.

2.5.Performance Estimates

Performance can be estimated when simulated data of varying parameters (such as CNR) is made available.

2.5.1.Test Data Description

Test data used are simulated and recorded navigation signal files.

Simulated Signal Generation:

MATLAB based Lab simulated signals for IRNSS are used for the testing of the developed algorithm. The signal is simulated using the signal structure described above in this document. Navigation data bits are generated randomly, then PRN code is used for the spreading and finally this composite modulates an IF carrier. The generated signal is then cut at a random time to give it a random delay. The process is repeated for many satellites and finally the signals for all the satellites are combined using different power coefficients. The noise is generated according to predefined CNR and then added to the signal. Finally the signal is quantized using 1-bit quantization.

Recorded Signals:

Recorded GPS signals available on internet. Two files which are having different signal parameters (sampling frequency, IF, PRNs, data type, quantization levels, storing format) are downloaded from the following web address:

http://gfix.dk/matlab-gnss-sdr-book/gnss-signal-records/

file1: compactdata.bin   Format:'ubit1'

file2: gioveAandB_short.bin   Format:'int8'

file3: IITJl1rxHBw_Run2.dat (Lab recorded file).

Table 3.1 Specifications of Receiver

<table>
<tr><th>S.No.</th><th>Parameters</th><th>Specifications</th></tr>
<tr><td>1.</td><td>Receiver (No. of Channels)</td><td>Selectable</td></tr>
<tr><td rowspan="3"></td><td>Implementation Complexity Acquisition
i) Cold</td><td>TBD
(To Be Determined)</td></tr>
<tr><td>ii) Warm</td><td>TBD</td></tr>
<tr><td>iii) Hot</td><td>TBD</td></tr>
<tr><td>3.</td><td>Update Rate</td><td>TBD</td></tr>
<tr><td rowspan="5"></td><td colspan="2">Carrier Phase :
Dynamic range $-\pi/2$ to $\pi/2$
Accuracy TBD</td></tr>
<tr><td colspan="2">Code Phase :
Dynamic range -1/2 chip to + 1/2 chip
Accuracy TBD</td></tr>
<tr><td colspan="2">Carrier Doppler frequency:
Dynamic range -125Hz to 125Hz
Accuracy TBD</td></tr>
<tr><td>Bit Error Rate</td><td>TBD</td></tr>
<tr><td>CNR Estimation</td><td>TBD</td></tr>
</table>

2.6.Practical Considerations

2.6.1.Numerical Computation Considerations

The expressions used in section 2.3.2 is used for numerical computation consideration.

In acquisition the total combination to search since we have considered ±10KHz Doppler at 500Hz step size. There will be 41 different carrier frequencies and 2046 (1023*2) different C/A Code Phase.

Hence total 41*2046=83886 combination.

For each of these combinations:

Number of multiplications = 2046.

Number of Additions = 2046-1 = 2045.

In the tracking process,

Number of correlations = 6 (2 for each of E, L and P)

For each of these correlations,

Number of multiplications = 1023 x N_s (Let 20) = 20460

Number of Additions = 20460-1 = 20459.

Other operations in tracking are to be done on a microprocessor excluding NCO. NCO computations depend upon the quantization levels.

2.6.2.Programming and Procedural Considerations

MATLAB is used as a programming Language for the implementation of the baseband processor.

Procedural considerations:

1. The main file “INITIALIZING_THE_RECEIVER” needs to be executed for starting up the product. Initial settings (which are stored in the file “initial_Settings”)and recorded signal file are read, probing of the signal is done as per the user’s wish (using the function “probeData”) and then baseband processing begins using the file “Processing” as shown in Fig. 2-12.

Title: Initialization of the Receiver (Block1)

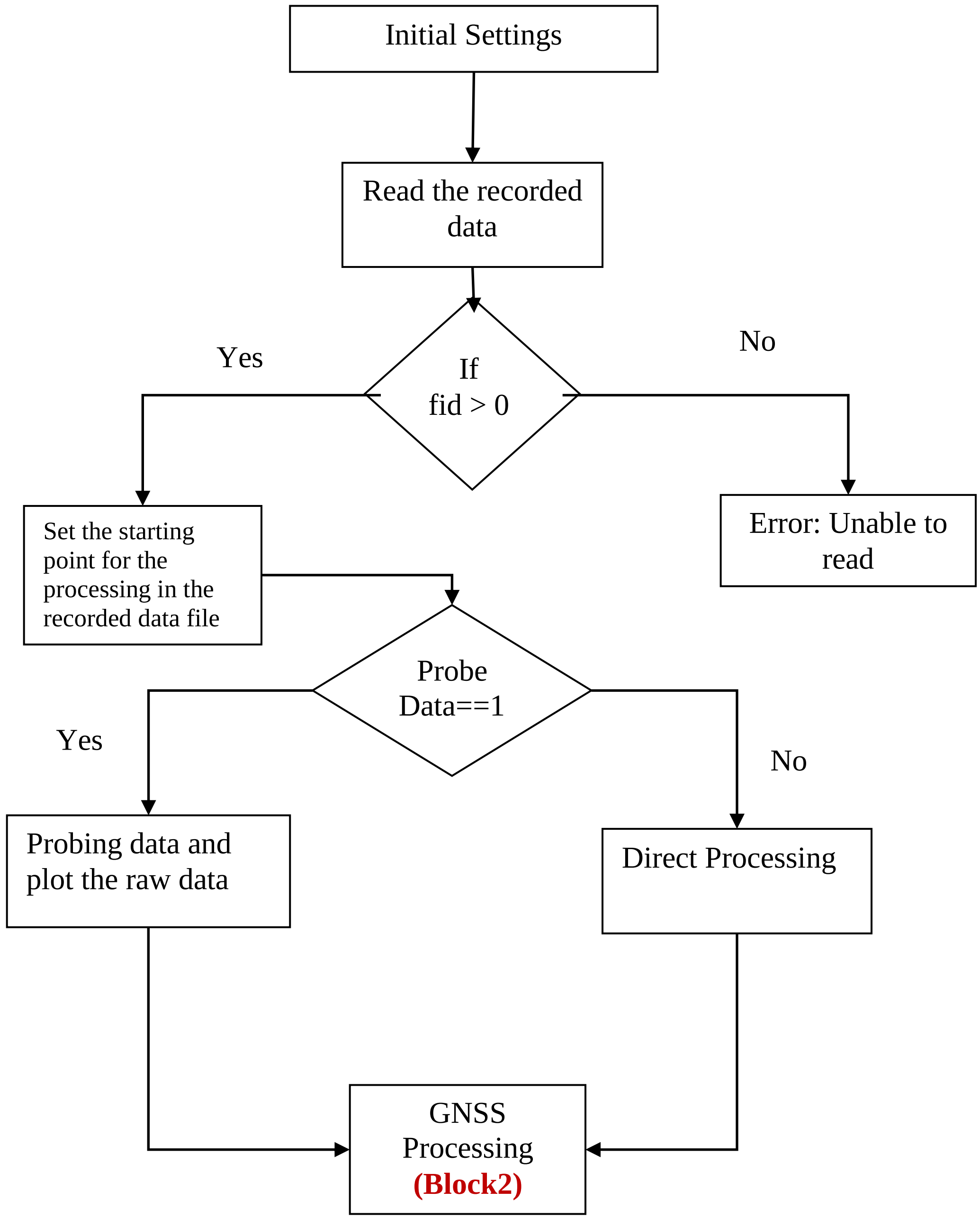

Figure 2-12 Flow Chart for Initialization of the Receiver

2. In Processing, first the structure of the results is initialized; where different acquisition, tracking and lock parameters are stored for analysis or for using them in Navigation Processor. Then, type of start is selected by user (Cold, Warm and Hot) (*ultimately, type of start will be updated by navigation processor*). In case of cold start, the function

"Initial_Acquisition" is called. In other cases, the function "tracking" is called which can call warm or hot start as per user's requirement. Processing is shown in Fig. 2-13.

Note: In standalone receiver where no navigation processor help is available, the user must select cold start only.

Title: Processing (Block2)

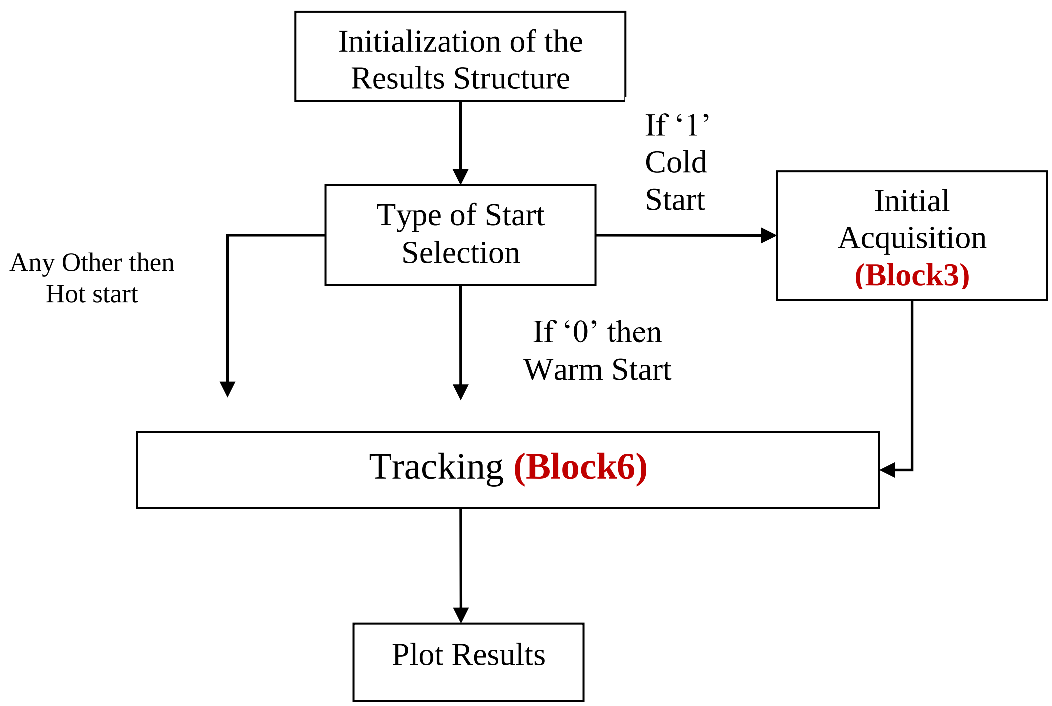

Figure 2-13 Baseband Processing

3. In the function "Initial_Acquisition" (fig 2-14), first, the selected incoming signal block is down-sampled. The reference code is generated at down-sampled rate by calling the function "Code_Generator". The frequency bins are generated using the pre-defined IF and Doppler search range. "NCO" is called for generating carrier at a particular frequency bin. Using the carrier, Doppler wipe-off is done and then correlation with the reference code is done (Serial Code-Phase search is performed). Repeating the process at different frequency bins, Acquisition Grid is obtained. Ratio of highest peak to 2^{nd} highest peak is used for deciding the presence of satellite. The process is repeated by incrementing the PRN until all the satellite are searched or satellites equal to no of channels are acquired.

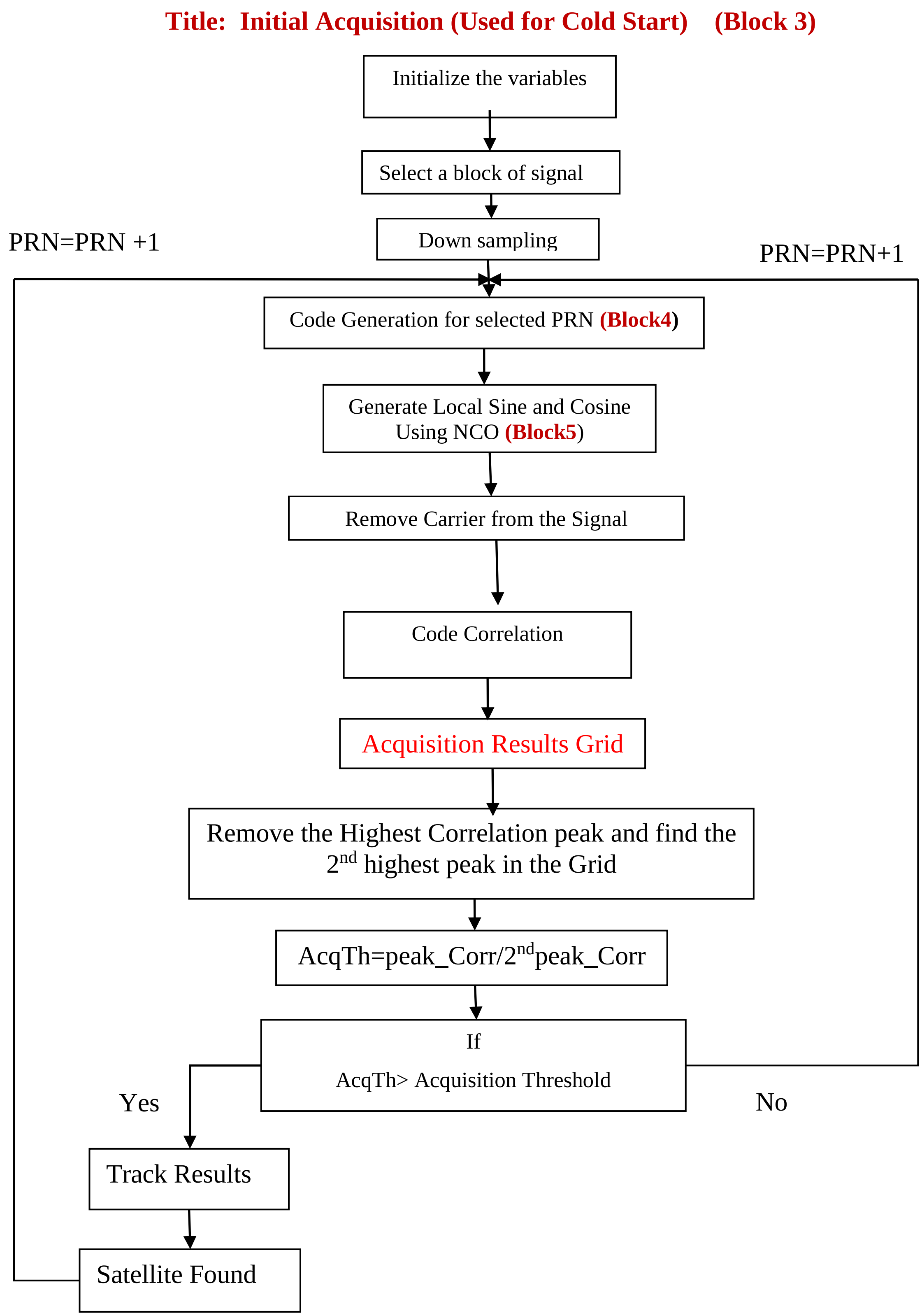

Figure 2-14 Flow Chart for Initial Acquisition (Used for Cold Start)

Title: Code Generator (Block 4)

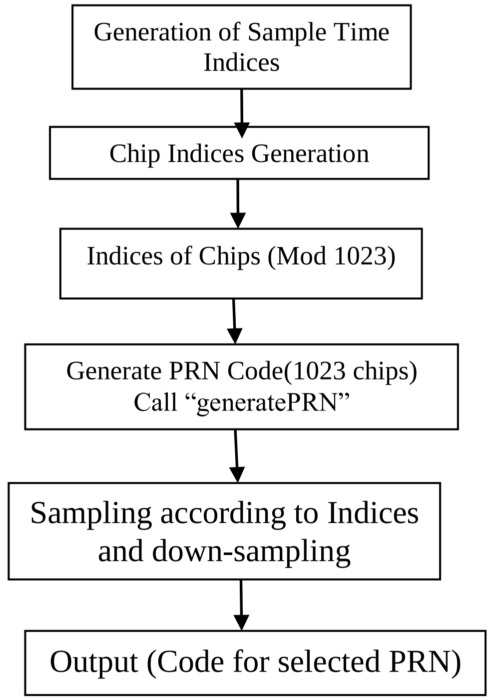

Figure 2-15 Flow Chart for Code Generator

Title: NCO Block (To generate Sine and Cosine Carrier) (Block 5)

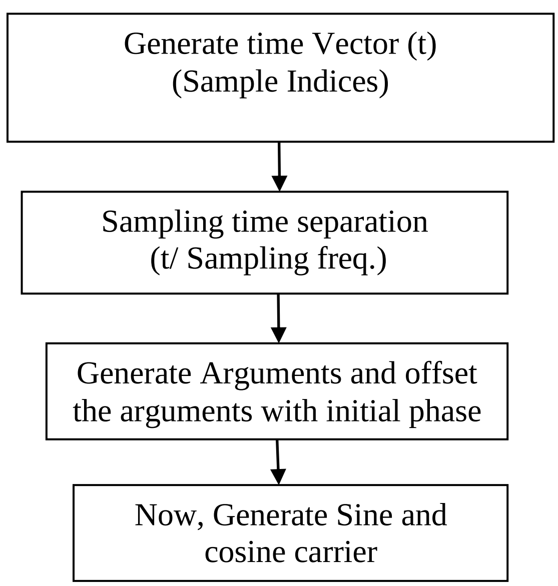

Figure 2-16 Flow Chart for NCO

4. In the function “tracking”, first the reference code is generated by calling “code_generator_tracking”. The acquisition status is checked and warm/hot acquisition is called if required. If no acquisition is required, then tracking starts (fig. 2-17).

Title: Tracking (Block6)

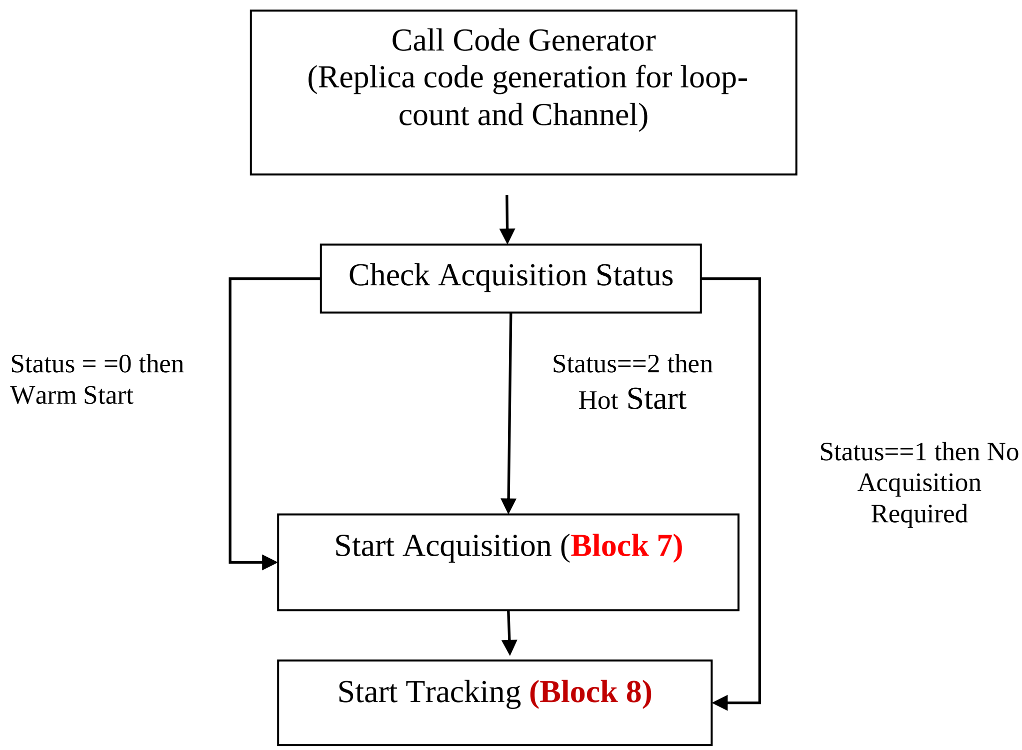

Figure 2-17 Flow Chart for Tracking

5. When warm/hot start are required the function “tracking” calls the function “Acquisition” (fig. 2-18). “Acquisition” performs warm or hot start as per the acquisition status. Warm start is similar as discussed in “Initial_Acquisition”, the difference is in Doppler search range (which is less) and the operation is performed only for the selected PRN. In hot start, which is fine frequency search, the code phase is already known, the frequency space is searched finely around the known approximate frequency.

Title: Acquisition (Block 7)

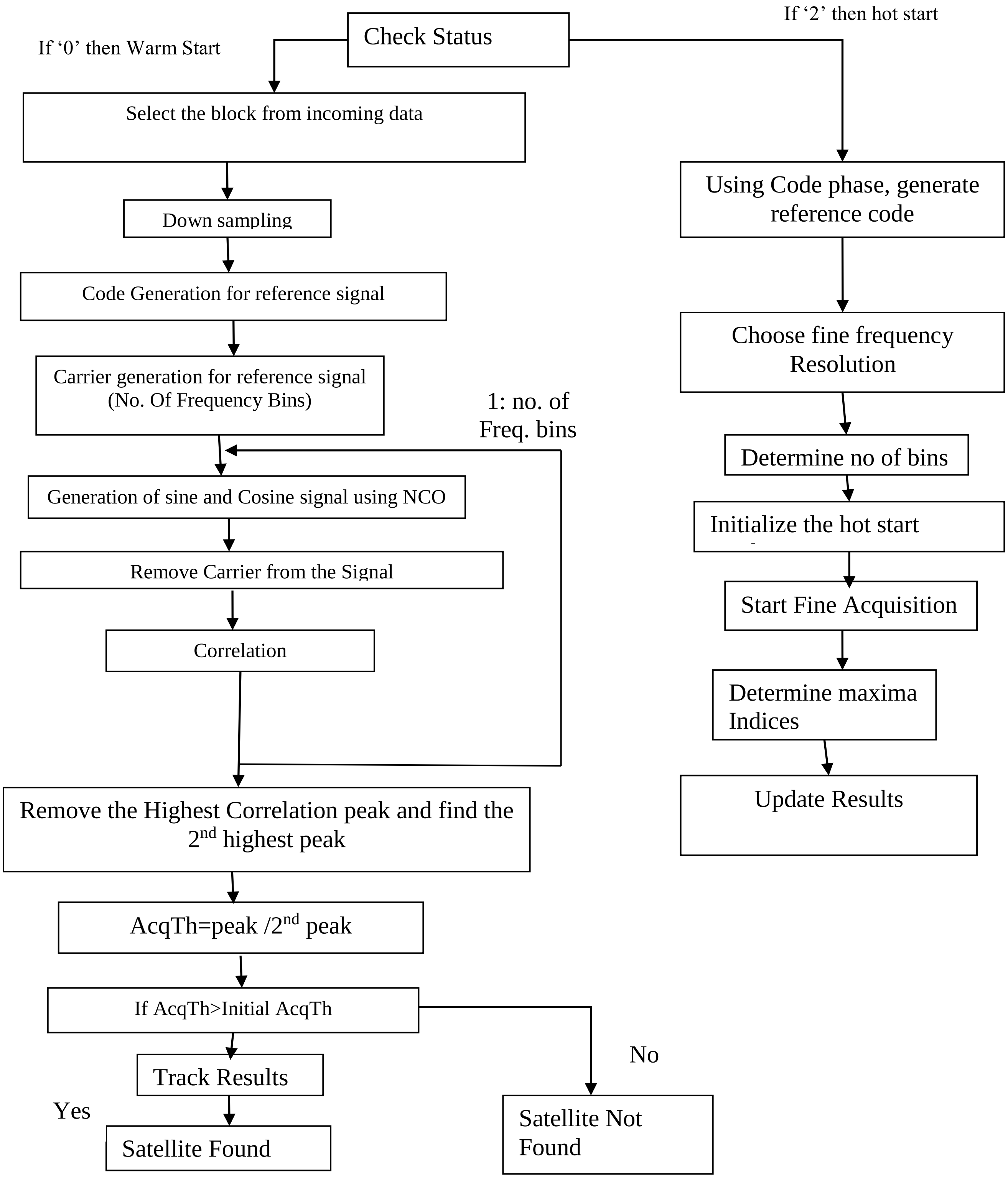

Figure 2-18 Flow Chart for Acquisition (Warm and Hot Start)

6. In "tracking"(when warm/hot start is not required), Early, Prompt and Late Codes are generated and correlated with carrier wiped-off signal to get correlation values I_E, Q_E, I_P, Q_P, I_L, Q_L as shown in figure 2-19. Then code and carrier tracking is done using these correlation values.

Title: Start Tracking (Block8)

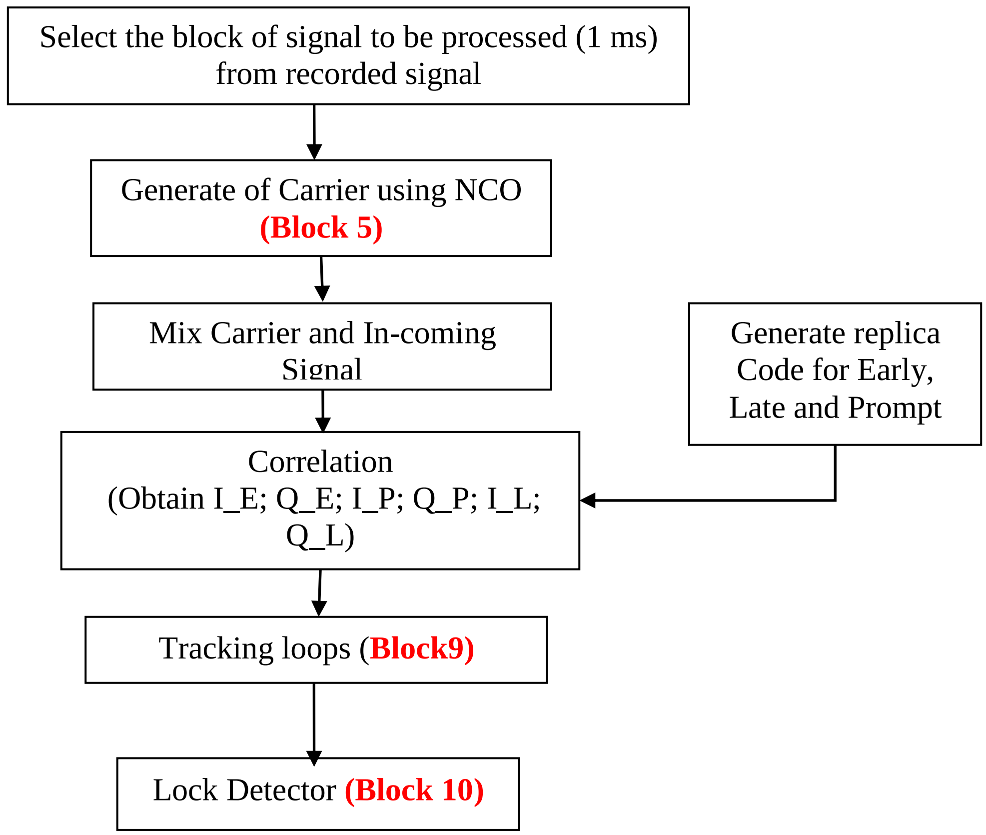

Figure 2-19 Flow Chart for Start Tracking

7. In Code tracking, envelope values for replica codes (Early, Prompt and Late) are calculated and code error (E-L) is observed. Depending on the sign of Code Error, code phase value (Prompt Delay at which the reference code is generated) is updated. In Carrier tracking, the correlation values for Prompt are used by phase and frequency discriminator to calculate the phase and frequency deviation between the incoming signal and carrier generated using NCO. Then these as filtered and updated (figure 2-20).

Title: Tracking Loop [Code Tracking and Carrier Tracking] (Block9)

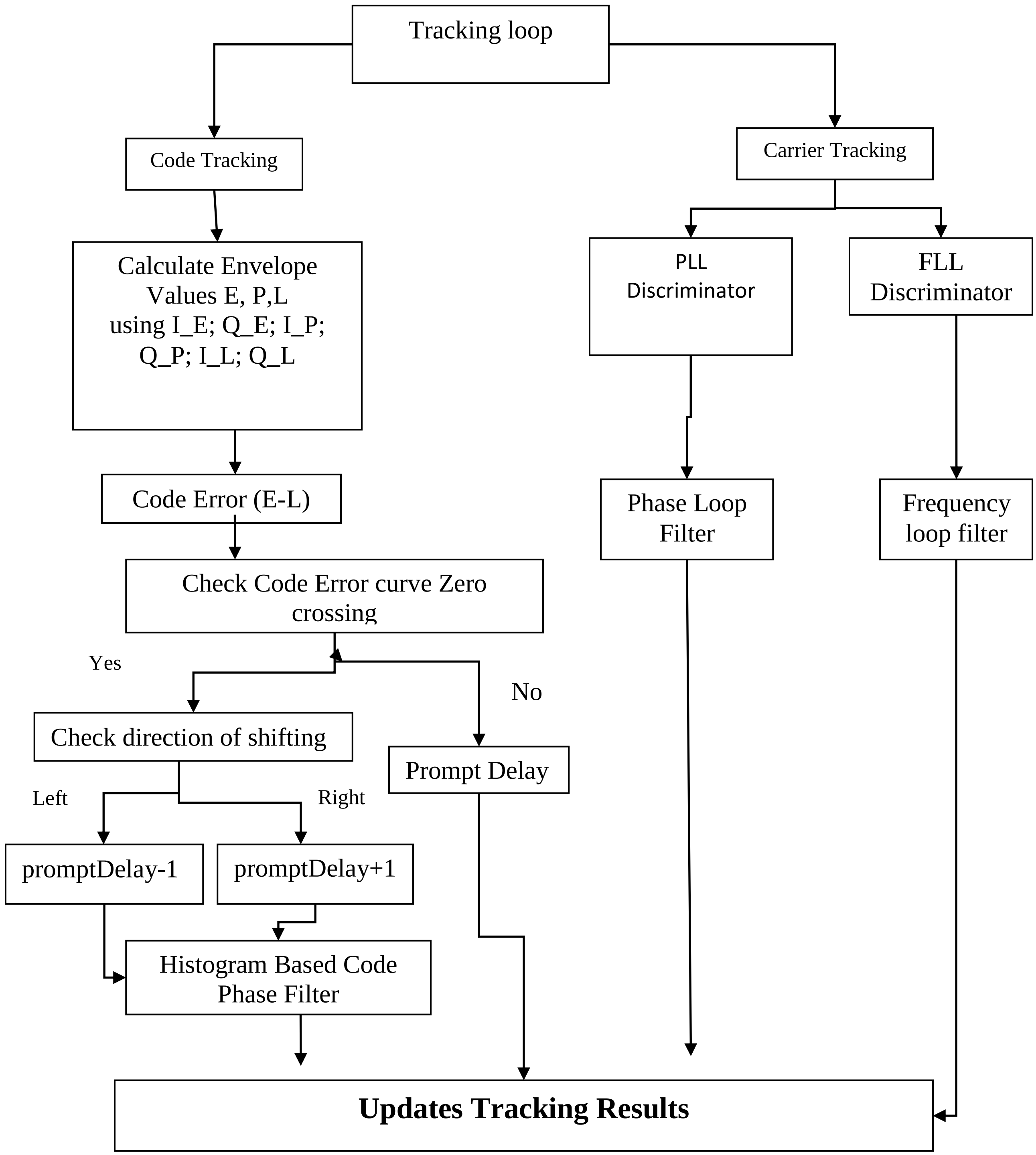

Figure 2-20 Flow Chart for Tracking Loops

8. File “Lock_Detectors”: After code and carrier tracking, the condition for lock is checked in which the last 20 values of Prompt Correlators are used for CNR estimation and also check the counts for sign change in prompt correlation values. Lock lost condition is checked based on CNR and sign changes and acquisition status is updated according to that (Figure 2-21).

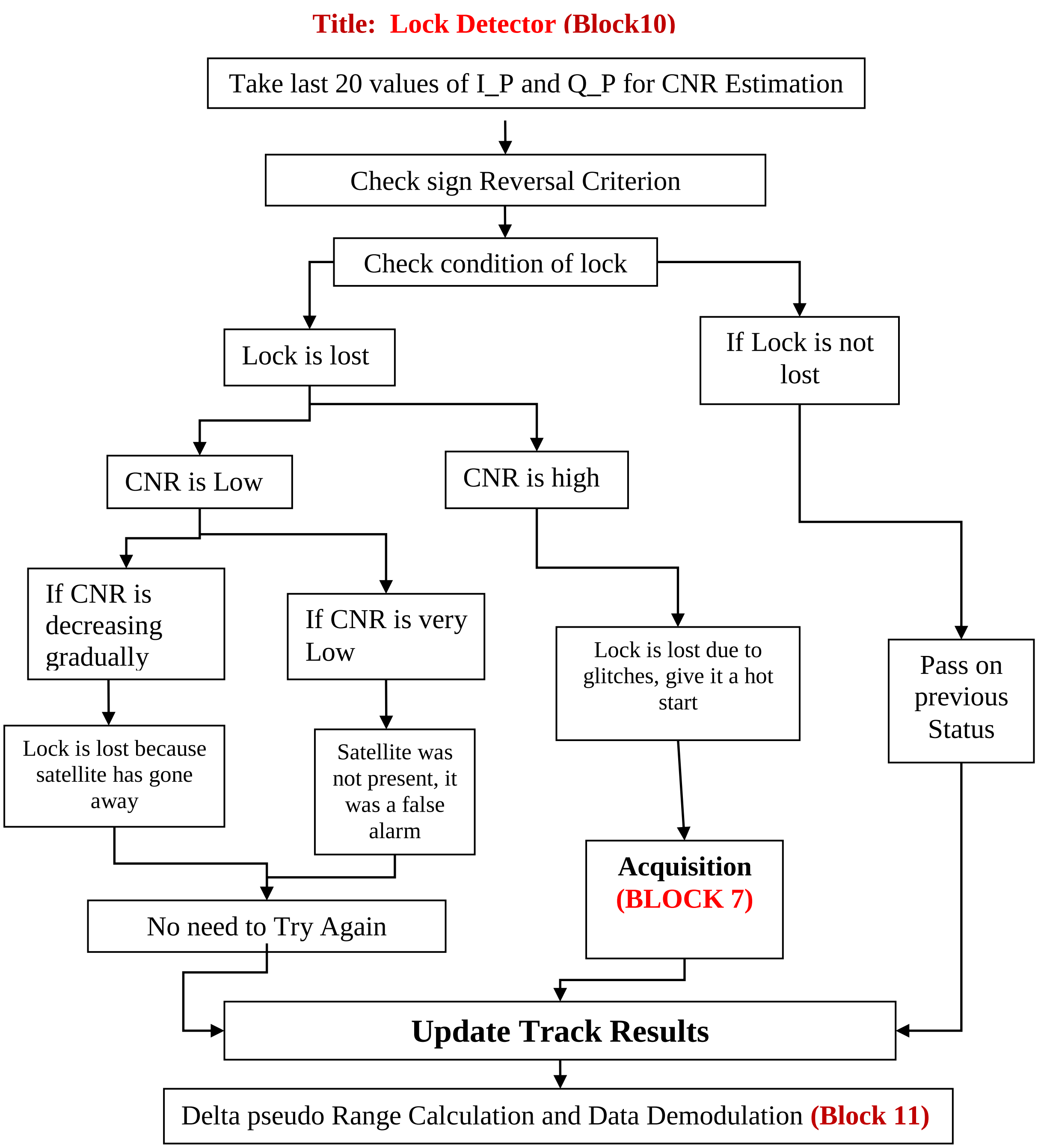

Figure 2-21 Flow Chart for Lock Detector

9. After a successful lock detection, Delta pseudo-range is calculated and navigation data is demodulated. First the condition for strong lock is ensured and then data boundaries are determined. Then delta pseudo-range is calculated as per its definition. Data bit is demodulated by averaging the 20 correlation values for the data bit.

Title: Delta Pseudo Range Calculation and Data Demodulation (Block11)

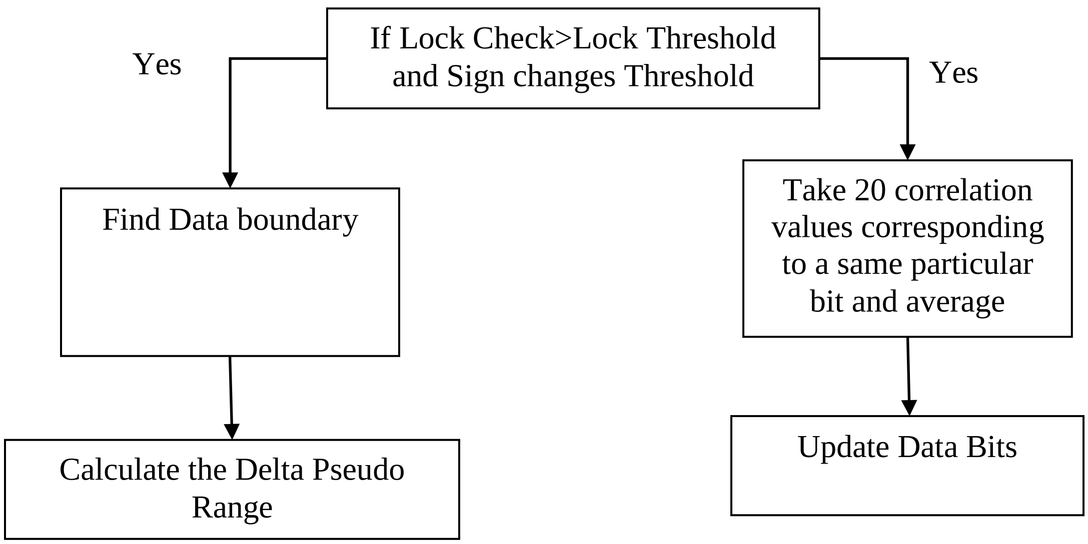

Figure 2-22 Flow Chart for Delta Pseudo Range Calculation and Data Demodulation

2.7.Validation

Validation of data has been done using following signals.

1. Simulated Signal (IRNSS)
2. GPS Recorded Signal (Taken From Internet)
3. GPS Recorded Signal (Recorded in Laboratory)

3. ASSUMPTIONS AND LIMITATIONS

3.1.Performance Assumptions

Carrier Doppler frequency range for Cold Start is ± 10 KHz.

Carrier Doppler frequency range for Warm Start is ± 5 KHz.
Carrier Doppler frequency range for Hot Start is TBD.

3.2.Potential Improvements

Optimization can be done once the enough data set is available. The potential improvement can be in Lock Detectors, Acquisition Threshold, Loop Filter parameters in Code and Carrier Tracking Loops. Quantification of the performance for finding the lower limit on CNR up to which algorithm can work satisfactorily.

4.REFERENCES

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