

## DESCRIPTION

## TITLE OF INVENTION:

SATELLITE POSITIONING SIGNAL RECEIVING METHOD AND DEVICE

## TECHNICAL FIELD

[0001]

The present invention relates to a signal receiving technique for receiving a satellite positioning signal transmitted from a satellite positioning system represented by a global positioning system (GPS) and, more particularly, relates to a receiving method and a receiving apparatus for receiving two kinds of signals having different frequencies.

## BACKGROUND ART

[0002]

A satellite positioning system depends on a passive measurement of satellite positioning signals transmitted by a plurality of artificial satellites. An onboard clock is used for generating a regular and usually continuous series of events often called "epoch". A random code or a pseudorandom code is repeated at a regular interval of the epoch. By receiving a spread-coded radio wave with a receiving apparatus, it is possible to measure a phase difference between a spread code generated by the clock timing of the receiving apparatus and a spread code of a received signal and measure a difference between a positioning satellite and the receiving apparatus.

[0003]

Examples of such a satellite positioning system include the Global Positioning System (GPS). In general, the GPS operates using a plurality of frequencies called L1, L2, L5, and the like centering respectively on 1575.42 MHz, 1227.6 MHz, and 1176.45 MHz. Each of these signals is modulated by each spread signals. As those skilled in the art can easily understand, a CA (Coarse Acquisition) code signal generated by a GPS

satellite navigation system is transmitted at a frequency of 1575.42 MHz (called L1 band) and has a spread code rate (a chip rate) of 1.023 MHz. Further, these signals are superimposed with data called navigation message. A data transmission rate of the signal is 50 bps. The signal having the spread code rate of 1.023 MHz and the data transmission rate of 50 bps is generally called "L1 C/A signal". In Figure 8, a signal structure of the L1 C/A signal is shown.

[0004]

Examples of the satellite positioning system include a Quasi Zenith Satellite System (QZSS) that is under development in Japan (Non Patent Literature 1). Like the GPS, the QZSS is about to be developed under the policy that the QZSS operates using a plurality of frequencies such as L1, L2, and L5 centering respectively on 1575.42 MHz, 1227.6 MHz, and 1176.45 MHz. In the QZSS, a frequency of E6 centering on 1278.75 MHz is also used. A "LEX signal" is transmitted at this frequency.

[0005]

In position determination by the satellite positioning system such as the GPS, a radio wave transmitted from a positioning satellite is received by a receiving apparatus on the ground. The distance between the satellite and the receiving apparatus is measured on the basis of a radio wave propagation time from the satellite to the receiving apparatus. Orbit information indicating the position of the positioning satellite itself and clock information meaning deviation of the time of the satellite itself are superimposed on the radio wave transmitted from the positioning satellite.

[0006]

The receiving apparatus can learn the position and the time of the satellite by demodulating the Orbit information and the clock information transmitted from the positioning satellite. The receiving apparatus determines the position of the receiving apparatus itself according to, for example, the method of trilateration using measured values of the distances between a plurality of satellites and the receiving apparatus and the positions and the times of the satellites.

[0007]

In Figure 9, the configuration of a satellite positioning system including a conventional satellite positioning receiving apparatus is shown. A receiving apparatus 902, which performs passive measurement, continuously receives satellite positioning signals from a plurality of positioning satellites 901a to 901d of a satellite positioning system 900 and performs positioning and the like. The satellite positioning receiving apparatus 902 applies, in a front end unit 9022, pre-processing to a signal input from a reception antenna unit 9021, converts the signal into a digital signal in an ADC unit 9023, and sends the digital signal to a data processing unit 9024.

[0008]

In Figure 10, the block configuration of a data processing unit of a conventional receiving apparatus is shown. A data processing unit 1000 includes one or a plurality of reception channels (in the figure, a channel 1 to a channel n). The data processing unit 1000 allocates one satellite positioning signal per each reception channel to satellite positioning signals transmitted from a plurality of satellites and performs continuous reception processing. The continuous reception processing means processing a target satellite positioning signal into a state in which a message included in the signal can be decoded while continuing tracking. In some cases, ranging (measurement of the distance between a satellite and the receiving apparatus) is performed simultaneously and in parallel.

[0009]

For the reception channels to perform the continuous reception processing, it is necessary to learn the frequency of a satellite positioning signal and the phase of a spread code. However, in general, since the frequency of the satellite positioning signal and the phase of the spread code fluctuate, when reception is started, the frequency and the phase cannot be acquired unless the frequency and the phase are searched.

[0010]

Concerning the frequency of the satellite positioning signal, since a Doppler effect caused by relative speed of the satellite and the receiving apparatus is added and there is also the influence of a frequency error of an internal transmitter of the receiving apparatus, the frequency is unknown. For the reception channels to shift to a continuously receivable state, it is necessary to search for a frequency obtained by adding a frequency due to the Doppler effect (a Doppler frequency) and the frequency error of the internal transmitter of the receiving apparatus to the frequency of the satellite positioning signal.

[0011]

Further, concerning the spread code, since the satellite positioning signal is spread by a repeated spread code, the satellite positioning signal cannot be received unless the same spread code sequence is correlated with the satellite positioning signal with the phase of the spread code sequence matched with the phase of the satellite positioning signal. On the other hand, a code rate of the spread code is usually in the order of MHz. It is difficult for an onboard clock of the receiving apparatus to stably operate at that accuracy for a long period. It is unlikely that a clock and time of the satellite that transmits the satellite positioning signal always coincide with each other. Therefore, it is nearly impossible to learn the phase of the spread code beforehand. Therefore, it is also necessary to search for the phase of the spread code.

[0012]

Therefore, for the reception channel to start the continuous reception of one satellite positioning signal, it is necessary to search for a frequency and the phase of the spread code in advance. This series of processing of the search is called "acquisition processing" or "acquisition". As a result of the acquisition processing, it is possible to acquire a frequency and a phase of the spread code for starting tracking processing.

[0013]

Note that, in the acquisition processing, basically, a search is performed concerning all frequencies (about  $\pm 5$  kHz in the case of an L1 C/A signal) at which satellite positioning signals could be present and phases of all spread codes (1023 chips in the case

of the L1 C/A signal). A frequency interval for performing the search is determined according to a characteristic of a satellite positioning signal. In the case of the L1 C/A signal, in general, the frequency interval is set to about 500 Hz. The phase of a spread code to be searched needs to be searched by the number of chips of the spread code. That is, when the length and the number of chips of the spread code increase, a calculation processing amount necessary for the acquisition processing as a whole increases.

[0014]

When the frequency and the phase of the spread code for starting tracking can be acquired by the acquisition, thereafter, the reception channel is controlled to keep a reception state while updating the frequency of the satellite positioning signal and the phase of the spread code. Specifically, each of the frequency and the phase of the spread code are separately controlled by a synchronization circuit explained below on the basis of continuously received satellite positioning signals using a general tracking circuit 1100 shown in Figure 11 to keep the reception state.

[0015]

First, concerning the frequency, in general, a phase synchronization circuit (Phase Lock Loop: PLL) 1101 is used. The PLL is a processing circuit that receives a cyclic signal as an input and performs stable signal reception processing according to feedback control. In the satellite positioning receiving apparatus, it is possible to acquire, as an output, a frequency  $f_{L1}$  sequentially updated with respect to the input satellite positioning signal with the frequency acquired by the acquisition set as an initial value.

[0016]

Next, concerning the phase of the spread code, in general, a delay synchronization circuit (Delay Lock Loop: DLL) 1104 is used. Like the PLL, the DLL is a processing circuit that receives a cyclic signal as an input and performs stable signal reception processing according to feedback control. In the satellite positioning receiving apparatus, it is possible to acquire, as an output, a phase  $\phi_{L1}$  of a spread code sequentially updated

with respect to the input positioning signal with the phase of the spread code acquired by the acquisition as an initial value.

[0017]

A series of processing for receiving a satellite positioning signal as an input and causing the satellite positioning signal to synchronize in the respective synchronization circuits using the frequency and the phase of the spread code is called "tracking processing" or "tracking". The tracking processing is performed at a specific cycle based on a characteristic of the satellite positioning signal. Every time the tracking processing is performed, an updated frequency and an updated phase of a spread code can be acquired. A message included in the satellite positioning signal is obtained from the tracking circuit as an output.

[0018]

Next, in a reception channel in which the tracking is being performed, it is possible to decode the message included in the satellite positioning signal. The decoding of the message is performed in a "decoding unit". In the reception channel in which the tracking is being performed, it is possible to measure the distance between the satellite and the receiving apparatus. This is called "ranging" and is performed in a "ranging unit". The principle of the ranging is a mechanism for reading a propagation time from a time difference from a spread code (generated on the receiving apparatus side), the phase of which is matched by the tracking with a spread code transmitted at known time on the satellite side, and multiplying the propagation time with light speed to measure a distance. Specifically, the principle of the ranging is as explained below.

[0019]

Time in the positioning satellite is managed by a precise satellite clock. Timing when the spread code is transmitted accurately conforms to the satellite clock. On the other hand, if the satellite positioning signal is tracked and the message decoding is performed, the satellite positioning signal receiving apparatus can learn accurate time

$T_s^k$

at an instance when the signal is transmitted. While tracking the satellite positioning signal from the positioning satellite, the satellite positioning signal receiving apparatus is generating a spread code same as the spread code of the positioning satellite in a matched phase. Since the spread code of the satellite positioning signal is repeated at a fixed cycle (e.g., in the case of the L1 C/A signal, 1 ms), a value of the phase

$$\phi_{L1}^k$$

of the spread code coinciding with the satellite positioning signal means transmission time of a signal at time  $T_u$  at an instance of reception at precision finer than 1 ms (in the case of the L1 C/A signal).

[0020]

Therefore, the satellite positioning signal receiving apparatus can learn a propagation time from the positioning satellite to the satellite positioning signal receiving apparatus on the basis of time

$$T_s^k$$

when the satellite positioning signal is transmitted from the satellite and the phase of the spread code

$$\phi_{L1}^k.$$

Actually, the onboard clock in the receiving apparatus is not as accurate as the clock of the positioning satellite. That is, a difference between the positioning satellite and the satellite positioning signal receiving apparatus is an apparent propagation time including an error. However, this is not a significant problem because a propagation time is measured with the same error for all positioning satellites (as explained below). Therefore, the distance measured on the receiving apparatus side is usually called "pseudorange". A calculation procedure of the pseudorange is shown in Figure 12.

[0021]

Figure 12 is a flowchart showing a conventional calculation procedure example of the pseudorange based on the L1 C/A signal. Meanings of variables in Figure 12 are as described below.

$\phi_{L1}^k$ : A phase of a spread code of a positioning satellite of a k-th reception channel [(0 to 1023) Chips]

$T_s^k$ : Transmission time of the positioning satellite of the k-th reception channel [sec]

$T_u$ : Reception time of the satellite positioning signal receiving apparatus [sec]

C: Light speed  $\approx 3 \times 10^8$  [m/sec]

$d^k$ : A pseudorange [m]

[0022]

In Figure 12, first, the calculation of the pseudorange is started from a state in which a target k-th reception channel is tracking a satellite positioning signal (S1201).

[0023]

$\phi_{L1}^k$

is a phase of a spread code of a satellite of the k-th reception channel. Since a frequency and a phase of a spread code updated every time by tracking can be acquired, the phase of the spread code acquired by the tracking is directly set as

$\phi_{L1}^k$

(S1202). Note that, in the case of the L1 C/A signal, the phase of the spread code could take a value equal to or larger than 0 and smaller than 1023.

[0024]

Next, when

$T_s^k$

is unknown (No in S1203),

$T_s^k$

is calculated. However, if decoding of a message is already performed, time when the satellite transmits a signal can be calculated from time information included in the message (S1204). For example, in the case of a message of the L1 C/A signal, time information represented by week second at every 6 seconds is included.

In the message, content from which transmission start time of a signal including the message is known is described. Therefore, if the message including the time information

is decoded at least once, it is possible to learn time when the L1 C/A signal, which is continuously received, is transmitted from the satellite. Thereafter, it is also possible to sequentially update the time.

This time is put as

$$T_s^k.$$

[0025]

Next, assuming that

$$T_s^k$$

is known (Yes in S1203),

$$T_u$$

is calculated. When tracking is not first tracking and

$$T_u$$

is already set (Yes in S1205), processing proceeds to S1207. However, when the tracking is the first tracking (No in S1205), the processing proceeds to S1206. The clock

$$T_u$$

in the receiving apparatus is set to an appropriate value with reference to a reception channel tracked first. For example, as a method of setting the clock  $T_u$ , if the reception channel tracked first is the k-th reception channel,

$$T_u$$

can be set to a value obtained by adding an appropriate value (e.g., 100 ms) to

$$T_s^k.$$

Thereafter, the clock in the receiving apparatus operates with reference to the value. Note that the appropriate value used here is equivalent to a common error for representing pseudoranges between satellites and the receiving apparatus. Therefore, basically, the appropriate value may be any value.

[0026]

When

$$\phi_{L1}^k, T_s^k, \text{ and } T_u$$

are calculated as explained above, the pseudorange  $d^k$  in the L1 C/A signal can be calculated by the following expression on the basis of the light speed  $C$  (S1207).

$$d^k = C \times \left\{ T_u - \left( T_s^k + \frac{\varphi_{L1}^k}{1023000.0} \right) \right\} \dots (1)$$

[0027]

As explained above, the position of the receiving apparatus can be calculated in a "positioning calculating unit" on the basis of results of ranging (pseudoranges) obtained in the respective reception channels. This is an overview of the "positioning" processing. In order to perform the positioning, usually, satellite positioning signals from four or more positioning satellites are necessary. By obtaining pseudoranges to the at least four positioning satellites, the error due to the "appropriate value" used in the setting of the clock in the receiving apparatus is eliminated.

## CITATION LIST

### Non Patent Literature

[0028]

Non Patent Literature 1: Japan Aerospace Exploration Agency: "Quasi Zenith Satellite System User Interface Specifications (IS-QZSS) version 1.1", July 31, 2009, Internet <URL: <http://qzss.jaxa.jp/is-qzss/>>

## SUMMARY OF INVENTION

### TECHNICAL PROBLEM

[0029]

Incidentally, as a satellite positioning signal broadcasted by a satellite positioning system, there is a signal not aimed at ranging itself but having a function of correcting and augmenting the distance between a satellite and a receiving apparatus obtained by the ranging and a positioning position of the receiving apparatus. This is referred to as "augmentation signal". Information included in the augmentation signal is referred to as

"augmentation information". In general, the augmentation information in the augmentation signal is included in a message portion.

[0030]

In order to decode the augmentation information from the augmentation signal with a general method, the receiving apparatus needs to allocate one reception channel to the augmentation signal with a method same as a method applied to a ranging signal and perform acquisition processing and tracking processing in a pertinent frequency band and decoding processing.

[0031]

However, a frequency band in which the augmentation signal is broadcasted and a spread code of the augmentation signal are often different from a frequency band and a spread code of a signal generally used for ranging. Compared with a processing ability and resources of a receiving apparatus that treats only a signal used for ranging, a receiving apparatus that treats the augmentation signal requires a larger processing ability and larger resources. A LEX signal is more special. In order to decode a message including a augmentation signal included in a LEX signal short code, first, it is necessary to receive a signal spread by a long code having a 2.5575MCps/410ms length. This is far longer than a signal spread by a 1.023MHz/1ms length spread code. Therefore, if it is attempted to perform acquisition processing and tracking processing for the LEX signal in a receiving apparatus assumed to treat L1 C/A, there is a problem in that components and processing increase to cause a large increase in costs.

## SOLUTION TO PROBLEM

[0032]

The present invention is a satellite positioning receiving apparatus of a satellite positioning system including one or more positioning satellites that transmit a first signal and a second signal having different frequencies, characterized in that the satellite positioning receiving apparatus applies conversion processing to a frequency and phase

information of the second signal on the basis of a frequency and phase information acquired when reception of the first signal is started or continuously performed.

[0033]

The satellite positioning receiving apparatus is characterized in that the satellite positioning receiving apparatus decodes message information included in the second signal on the basis of the converted frequency and the converted phase information of the second signal.

[0034]

The satellite positioning receiving apparatus is characterized in that the satellite positioning receiving apparatus continuously performs tracking of the second signal on the basis of the converted frequency and the converted phase information of the second signal.

[0035]

The satellite positioning receiving apparatus is characterized in that the satellite positioning receiving apparatus measures a distance between the positioning satellite and the satellite positioning receiving apparatus on the basis of the frequency and the phase information of the first signal or the converted frequency and the converted phase information of the second signal.

[0036]

The present invention is a satellite positioning signal receiving method in a satellite positioning system including a positioning satellite that transmits a first signal and a second signal having different frequencies and a satellite positioning receiving apparatus, characterized in that the satellite positioning receiving apparatus converts a frequency and phase information of the second signal on the basis of a frequency and phase information acquired when reception of the first signal is started or continuously performed.

## ADVANTAGEOUS EFFECTS OF INVENTION

[0037]

With the satellite positioning signal receiving method and the satellite positioning signal receiving apparatus according to the present invention, it is possible to provide a method and the like that reduce a calculation processing amount in acquisition processing and tracking processing of satellite positioning signals having two different frequencies and reduce costs required for calculation processing components.

## BRIEF DESCRIPTION OF DRAWINGS

[0038]

[Figure 1] Figure 1 is an explanatory diagram for explaining the schematic configuration of a satellite positioning system including a satellite positioning signal receiving apparatus according to an embodiment of the present invention.

[Figure 2] Figure 2 is an explanatory diagram for explaining the block configuration of the satellite positioning signal receiving apparatus according to the embodiment of the present invention.

[Figure 3] Figure 3 is a flowchart for explaining a processing flow in the satellite positioning signal receiving apparatus according to the embodiment of the present invention.

[Figure 4] Figure 4 is an explanatory diagram for explaining a relation between an L1 C/A signal and a LEX signal in the satellite positioning system according to the embodiment of the present invention.

[Figure 5] Figure 5 is an explanatory diagram for explaining the schematic configuration of a satellite positioning system including a satellite positioning signal receiving apparatus according to another embodiment of the present invention.

[Figure 6] Figure 6 is an explanatory diagram for explaining the block configuration of the satellite positioning signal receiving apparatus according to the other embodiment of the present invention.

[Figure 7] Figure 7 is an explanatory diagram for explaining a signal generating circuit in a satellite positioning system according to an embodiment of the present invention.

[Figure 8] Figure 8 is an explanatory diagram for explaining the signal structure of a conventional L1 C/A signal.

[Figure 9] Figure 9 is an explanatory diagram for explaining the configuration of a satellite positioning system including a conventional satellite positioning receiving apparatus.

[Figure 10] Figure 10 is an explanatory diagram for explaining the block configuration of a data processing unit of the conventional receiving apparatus.

[Figure 11] Figure 11 is an explanatory diagram for explaining the block configuration of a conventional tracking circuit.

[Figure 12] Figure 12 is a flowchart for explaining a conventional calculation procedure of a pseudorange.

## DESCRIPTION OF EMBODIMENTS

[0039]

Modes for carrying out a satellite positioning signal receiving method and a satellite positioning signal receiving apparatus according to the present invention are explained in detail below with reference to the drawings.

### Embodiment 1

[0040]

In Figure 1, the schematic configuration of a satellite positioning system including a satellite positioning signal receiving apparatus according to an embodiment of the present invention is shown. In the embodiment of the present invention, a LEX signal is treated. A QZSS (Quasi Zenith Satellite System) that transmits the LEX signal is adopted as a model of the satellite positioning system.

[0041]

In Figure 1, an L1 C/A signal and a LEX signal broadcasted from each of positioning satellites 101a to 101d of a QZSS system 100 propagate in the outer space and

the atmosphere and reach a satellite positioning receiving apparatus 102. Carrier wave frequencies of the L1 C/A signal and the LEX signal having reached the receiving apparatus 102 are converted respectively into frequencies (intermediate frequencies) that can be easily treated (referred to as down-conversion or down-convert). The intermediate frequencies are different depending on a design concept of a receiving apparatus. In this specification, for convenience, the intermediate frequency of the L1 C/A signal is represented as

$$f_{IFL1}$$

and the intermediate frequency of the LEX signal is represented as

$$f_{IFE6}.$$

Thereafter, the down-converted signals are respectively quantized by ADC units 1023a and 1023b, sent to a data processing unit 1024, and subjected to reception processing.

[0042]

Next, the detailed configuration of the data processing unit 1024 in Figure 1 is shown in Figure 2.

[0043]

In Figure 2, in general, for a positioning receiving apparatus to receive signals from a plurality of positioning satellites, a plurality of reception channels are present in a data processing unit. However, in this specification, for understanding of the invention and convenience of explanation, only the operation in one reception channel is explained. The embodiment is illustratively explained as an embodiment in which a message of a LEX signal is decoded.

[0044]

In Figure 2, a data processing unit 200 is illustratively configured by an L1 acquisition unit 201 that performs acquisition processing of an L1 C/A signal, an L1 tracking unit 202 that performs tracking of the L1 C/A signal, an L1 decoding unit 203 that performs decoding of the L1 C/A signal, an L1-E6 conversion processing unit 204 that performs conversion processing from a frequency and a phase of a spread code of the

L1 C/A signal to a frequency and a phase of a spread code of a LEX signal, and an E6 decoding unit 205 that performs decoding of the LEX signal.

Note that, in the case of a satellite positioning receiving apparatus of a plurality of reception channels, these constituent elements are included as constituent elements of one reception channel. In some cases, it is also possible to adopt a configuration including a "ranging unit" and one "positioning calculating unit" in each channel. In this case, as the "ranging unit" and the "positioning calculating unit", configurations common to a data processing unit of a general receiving apparatus can be adopted.

[0045]

In Figure 3, a processing flow in the data processing unit 200 is shown.

[0046]

First, the data processing unit 200 starts processing in S301. After acquiring an initial value  $f_{L1}$  of a frequency of a satellite positioning signal and an initial value  $\phi_{L1}$  of a phase of a spread code in S302, the data processing unit 200 performs acquisition processing for the L1 C/A signal (S303). The acquisition processing performs a correlation calculation with an input satellite positioning signal on the basis of the acquired  $f_{L1}$  and  $\phi_{L1}$  and determines success or failure of acquisition according to a magnitude of a correlation value (S304). Unless the acquisition of  $f_{L1}$  and  $\phi_{L1}$  used in tracking is successful (Yes in S304), the data processing unit 200 returns to S303 and performs the acquisition processing. During the acquisition processing, the data processing unit 200 gradually changes  $f_{L1}$  and  $\phi_{L1}$  and sets  $f_{L1}$  and  $\phi_{L1}$  at the time when a highest correlation value as a frequency and a phase of a spread code at a point in time of acquisition success and as initial values of a frequency and a phase of a spread code used in tracking thereafter (S305).

[0047]

Note that, as algorithms such as a method of gradually changing  $f_{L1}$  and  $\phi_{L1}$  and a determination standard of success or failure of acquisition, conventionally used acquisition algorithms can be adopted. As a result of the acquisition processing, it is possible to

acquire the frequency  $f_{L1}$  and the phase  $\phi_{L1}$  of the spread code for tracking the L1 C/A signal.

[0048]

When the frequency and the phase of the spread code used in tracking first are determined by the acquisition of the L1 C/A signal described above, the data processing unit 200 ends the acquisition once. Subsequently, the data processing unit 200 performs tracking for the L1 C/A signal (S305). First, the data processing unit 200 sets  $f_{L1}$  obtained by the acquisition as a frequency of the satellite positioning signal and sets  $\phi_{L1}$  obtained by the acquisition as a phase of a spread code of the satellite positioning signal to perform tracking processing.

[0049]

As an algorithm used in tracking, a conventionally used known tracking algorithm can be used. The frequency and the phase of the spread code are sequentially updated according to the tracking processing, to which the L1 C/A signal is input, to be new  $f_{L1}$  and  $\phi_{L1}$ .

[0050]

Note that a frequency at which tracking of a signal is performed is specifically a frequency obtained by adding a Doppler frequency to an intermediate frequency. The Doppler frequency is a value determined by relative speed of a positioning satellite and a satellite positioning receiving apparatus and a frequency of transmission. That is, even if the L1 C/A signal and the LEX signal are transmitted from the same positioning satellite, since frequencies of transmission are different in the L1 C/A signal and the LEX signal, the Doppler frequency is also different values.

[0051]

In the tracking processing of the L1 C/A signal, unless some abnormality occurs in a reception state (Yes in S306), the data processing unit 200 assumes that a reception state is correct and continues the tracking processing (S306). When the tracking processing of the L1 C/A signal is not correctly continued because of some cause (No in S306), the data

processing unit 200 returns to the acquisition processing (S303) and, after the acquisition processing ends, performs tracking again, repeatedly.

While the tracking processing of the L1 C/A signal is continued, the data processing unit 200 performs, in a decoding unit, message decoding of the L1 C/A signal (S307).

[0052]

Subsequently, while the tracking of the L1 C/A signal is continued, if time information is acquired at least once (S309), the data processing unit 200 performs L1-E6 conversion processing (S310) on the basis of the time information and  $f_{L1}$  and  $\phi_{L1}$  (S308). Note that it is sufficient to acquire the time information once while the tracking is continued.

[0053]

In the L1-E6 conversion processing, two kinds of processing explained below are performed.

(Processing A) Conversion processing from a frequency of the L1 C/A signal to a frequency of the LEX signal

(Processing B) Conversion processing from a phase of a spread code of the L1 C/A signal to a phase of a spread code of the LEX signal

[0054]

Note that the "spread code of the LEX signal" described above indicates a short code of a 4 ms cycle into which a message of the LEX signal is CSK-modulated. It is a characteristic of the present invention not to perform reception of a long code unlike the conventional technique.

[0055]

Conversion from a frequency of the L1 C/A signal into a frequency of the LEX signal (the processing A explained above) is performed on the basis of the following Expression (2):

$$f_{E6} = \frac{E_6}{L_1} * (f_{L1} - f_{IFL1}) + f_{IFE6} \dots (2)$$

where,

$f_{E6}$ : a frequency of the LEX signal [Hz]

$f_{L1}$ : a frequency of the L1 C/A signal [Hz]

$f_{IFE6}$ : an intermediate frequency of the LEX signal [Hz]

$f_{IFL1}$ : an intermediate frequency of the L1 C/A signal [Hz]

$E_6$ : a center frequency of the LEX signal  $\equiv 1278750000$  [Hz]

$L_1$ : a center frequency of the L1 C/A signal  $\equiv 1575420000$  [Hz].

[0056]

The above Expression (2) indicates that the frequency  $f_{E6}$  of the LEX signal can be calculated using the frequency  $f_{L1}$  of the L1 C/A signal, the center frequency  $f_{IFL1}$  of the L1 C/A signal, the intermediate frequency  $f_{IFE6}$  of the LEX signal, the center frequency  $L_1$  of the L1 C/A signal, and the center frequency  $E_6$  of the LEX signal.

Here,  $L_1$  is a known value (1575.42 MHz) and  $E_6$  is a known value (1278.75 MHz). As  $f_{IFL1}$  and  $f_{IFE6}$ , peculiar known values can be used according to a design concept of a receiving apparatus.

Since  $f_{L1}$  is the frequency of the L1 C/A signal, the frequency  $f_{L1}$  used in tracking only has to be directly used.

[0057]

As explained above, the conversion processing from the frequency of the L1 C/A signal into the frequency of the LEX signal is performed on the basis of the above Expression (2).

[0058]

The conversion from the phase of the spread code of the L1 C/A signal into the phase of the spread code of the LEX signal (the processing B explained above) is performed on the basis of the following Expression (3):

$$\phi_{E6} = \left( \frac{\phi_{L1}}{R_{L1}} + kT_{L1} \right) * R_{E6} \quad \dots (3)$$

where, k takes any one value among 0, 1, 2, and 3,

$\phi_{E6}$ : a phase of a spread frequency of the LEX signal [Chip]

$\phi_{L1}$ : a phase of a spread code of the L1 C/A signal [Chip]

$R_{L1}$ : a spread code chip rate of the L1 C/A signal  $\equiv 1023000$  [Cps]

$T_{L1}$ : a spread code cycle of the L1 C/A signal  $\equiv 0.001$  [sec]

$R_{E6}$ : a spread code chip rate of the LEX signal  $\equiv 2557500$  [Cps].

[0059]

The above Expression (3) indicates that the phase  $\phi_{E6}$  of the spread code of the LEX signal can be calculated using the phase  $\phi_{L1}$  of the spread code of the L1 C/A signal, the chip rate  $R_{L1}$  of the spread code of the L1 C/A signal, the cycle  $T_{L1}$  of the spread code of the L1 signal, and the chip rate  $R_{E6}$  of the spread code of the LEX signal.

Here,  $R_{L1}$  is a known value (1.023 MCps),  $T_{L1}$  is a known value (0.001 sec), and  $R_{E6}$  is a known value (2.5575 MCps). Since  $\phi_{L1}$  is the phase of the spread code of the L1 C/A signal, the phase  $\phi_{L1}$  of the spread code used for tracking can be directly used.

[0060]

Note that k is a value that changes according to spread code cycles of two signals. In the case of L1 C/A and LEX, k is an integer that takes a value of [0, 3]. That is, k is updated at every 1 ms to 0, 1, 2, 3, 0, 1, 2, 3, 0, .... The value of k is determined after the time information is acquired by the message decoding of the L1 C/A signal. Specifically, the value of k is explained with reference to a relation between the L1 C/A signal and the LEX signal shown in Figure 4.

[0061]

In Figure 4, time when a currently received satellite positioning signal is transmitted is represented as  $t_x$  [sec]. The time  $t_x$  can be calculated, after the tracking processing of the L1 C/A signal, according to message decoding, with reference to time information included in a message at a rate of once in 6 seconds, from the number of times

a spread code is repeated and the phase  $\phi_{L1}$  of the spread code of the L1 C/A signal being tracked.

[0062]

Next, time when the spread code of the L1 C/A signal and the spread code of the LEX signal are simultaneously started is defined as  $t_0$  [sec]. Transmission of the L1 C/A signal and the LEX signal is simultaneously started with reference to the beginning of a week. Since the spread code cycle  $T_{E6}$  of the LEX signal is 4 ms and the spread code cycle  $T_{L1}$  of the L1 C/A signal is 1 ms, after the beginning of the week, the spread code of the L1 C/A signal and the spread code of the LEX signal simultaneously start accurately at every 4 ms. That is, at time of a multiple of 4 ms, the spread code of the L1 C/A signal and the spread code of the LEX signal are always simultaneously started with reference to the beginning of the week. In Figure 4, in the nearest past before  $t_x$ , time when the spread code of the L1 C/A signal and the spread code of the LEX signal simultaneously start is always present in four cycles in the past of the spread code of the L1 C/A signal. That is, time in the nearest past, which is a multiple of 4 ms, before  $t_x$  is  $t_0$ .

[0063]

The value of  $k$  represented by the above Expression (3) is a number of cycles of the spread code of the L1 C/A signal included between  $t_x$  and  $t_0$ . That is, the value of  $k$  is updated from  $k=0$  at every 1 ms with reference to time when the spread code of the L1 C/A signal and the spread code of the LEX signal are simultaneously started.

[0064]

As explained above, the conversion from the phase of the spread code of the L1 C/A signal to the phase of the spread code of the LEX signal is performed.

[0065]

When the L1-E6 conversion processing ends in S310, the data processing unit 200 proceeds to S311 and performs LEX message decoding.

[0066]

Referring back to Figure 2, the frequency and the phase of the spread code of the LEX signal calculated by the L1-E6 conversion processing unit 204 is passed to the E6 decoding unit 205 and used for decoding the message included in the LEX signal in the E6 decoding unit 205.

Note that, in Figure 2, a flow of a signal from the L1 tracking unit 202 to the E6 decoding unit 205 through the L1-E6 conversion processing unit 204 is represented by a dotted line. This means that what is passed between blocks is not satellite positioning signals input to the data processing unit but is a frequency and a phase of a spread code calculated on the basis of the satellite positioning signals and time information based on a message decoded by the decoding unit.

[0067]

The data processing unit 200 decodes, in the E6 decoding unit 205, on the basis of the converted frequency and the converted phase of the spread code of the LEX signal, a message included in the signal. To actually decode the message of the LEX signal, it is necessary to learn start time of the LEX spread code at every 4 ms. The start time corresponds to the spread code simultaneous start time  $t_0$  used in calculating the phase of the spread code of the LEX signal in the L1-E6 conversion processing unit 204. The spread code simultaneous start time  $t_0$  can be represented by the following expression using the converted phase  $\phi_{E6}$  of the spread code of the LEX signal:

$$t_0 = t_x - \frac{\phi_{E6}}{R_{E6}} \dots (4)$$

[0068]

That is, the start time of the LEX spread code (= the spread code simultaneous start time)  $t_0$  can be calculated using the transmission time  $t_x$  of the currently received signal, the converted phase  $\phi_{E6}$  of the spread code of the LEX signal, and the chip rate  $R_{E6}$  of the spread code of the LEX signal.

[0069]

Eventually, the message decoding of the LEX signal can be performed by, from the message of the LEX signal at every 4 ms from  $t_0$ , removing a frequency component superimposed on the LEX signal on the basis of the converted frequency of the LEX signal and decoding the CSK-modulated short code.

[0070]

As explained above, it is possible to directly decode the message included in the LEX signal on the basis of the converted frequency and the converted phase of the spread code of the LEX signal.

[0071]

As more advanced processing, it is also possible to allocate one reception channel to the LEX signal again on the basis of the converted frequency and the converted phase of the spread code of the LEX signal and start tracking of a long code of the LEX signal. In this case, there is an advantage that it is possible to save acquisition processing by the long code of the LEX signal necessary for starting the tracking of the long code of the LEX signal by a normal conventional technique.

[0072]

In this case, the message included in the short code of the LEX signal is decoded while tracking processing of the long code of the LEX signal is continued.

[0073]

Another characteristic of the present invention resides in omitting the acquisition processing and the tracking processing of the LEX signal and decoding the augmentation information included in the LEX signal from the frequency and the phase of the spread code acquired by the acquisition processing and the tracking processing of the L1 C/A signal. The present invention makes use of the fact that, although frequencies of transmission are different, since the L1 C/A signal and the LEX signal are transmitted from the same satellite, spread codes of two signals are periodically transmitted at the same timing.

[0074]

In the best mode for carrying out the invention explained above, it is suitable that the L1 C/A signal is continuously received, a frequency and a phase of a spread code of the LEX signal is calculated from a frequency and a phase of a spread code of the L1 C/A signal, and the augmentation information included in the LEX signal is decoded from the frequency and the phase of the spread code of the LEX signal.

## Embodiment 2

[0075]

In the embodiment explained above, the configuration in which the E6 decoding unit is provided in the data processing unit is explained. However, the present invention is not limited to this. For example, as shown in Figure 5, it is also possible to set an E6 decoding unit 5025 as a system on the outside of a data processing unit 5024. That is, it is conceivable to pass, as an output of the data processing unit 5024, the frequency and the phase of the spread code of a LEX signal to the E6 decoding unit 5025 present in another system. In this case, in a receiving apparatus, a satellite positioning signal output from an ADC unit 5023b and the converted frequency and the converted phase of the spread code of the LEX signal are output and separately passed to the E6 decoding unit (dedicated machine) 5025.

Note that, in this case, as indicated by a data processing unit 600 illustratively shown in Figure 6 as a detailed block diagram of the data processing unit 5024, an L1 C/A signal only has to be input to the data processing unit 600 and an E6 signal does not need to be input to the data processing unit 600.

## Embodiment 3

[0076]

In the above explanation, the L1 C/A signal and the LEX signal are treated as the two different signals. However, the present invention is not limited to the combination of the L1 C/A signal and the LEX signal. If signals to be treated are satellite positioning

signals having two different frequencies transmitted from the same positioning satellite, similarly, it is possible to acquire, on the basis of a satellite positioning signal for which a relatively light processing ability is required concerning the acquisition processing and the tracking processing, information concerning a satellite positioning signal for which a relatively high processing ability is required concerning the acquisition processing and the tracking processing.

#### Embodiment 4

[0077]

Because of a difference between frequencies in an L1 band in which the L1 C/A signal is carried and an E6 band in which the LEX signal is carried, when the two signals propagate in the outer space and the atmosphere, the two signals are affected by the ionosphere present above the earth and, in general, a difference occurs in a propagation distance between the signals having the two frequencies (this is referred to as "ionosphere delay error"). The ionosphere delay error also affects a phase of the spread code of the L1 C/A signal and a phase of the spread code of the LEX signal. Therefore, when the phase of the spread code of the L1 C/A signal is converted into the phase of the spread code of the LEX signal, it is more suitable that the ionosphere delay error that occurs between the two frequencies is taken into account.

A difference due to the ionosphere delay error can be predicted according to an academic model such as a Klobuchar model. Therefore, in this case, the conversion of the phase of the spread code of the L1 C/A signal into the phase of the spread code of the LEX signal represented by the above Expression (3) can be represented as indicated by the following expression including  $\varphi_K$ , which is a term representing a phase difference between the spread code of the L1 C/A signal and the spread code of the LEX signal due to the ionosphere delay error:

$$\varphi_{E6} = \left( \frac{\varphi_{L1}}{R_{L1}} + kT_{L1} \right) * R_{E6} + \varphi_K \quad \dots (5)$$

where,

$\psi_K$ : a phase difference between the spread code of the L1 C/A signal and the spread code of the LEX signal due to the ionosphere delay error.

#### Embodiment 5

[0078]

In the embodiments explained above, after the L1 C/A signal and the LEX signal are input to the receiving apparatus, the signals are respectively ADC-converted in the ADC unit and input to the data processing unit. However, because of the influence of a difference of respective electric routes of the signals, an error sometimes occurs in the phase of the spread code of the L1 C/A signal and the phase of the spread code of the LEX signal.

Therefore, when the phase of the spread code of the L1 C/A signal is converted into the phase of the spread code of the LEX signal, it is more suitable that the error that occurs between the two frequencies is taken into account.

[0079]

In this case, it is possible to predict several values as the error, perform conversion taking into account the respective values, and obtain a plurality of results. As a specific processing procedure, the conversion of the phase of the spread code of the L1 C/A signal into the phase of the spread code of the LEX signal represented by the above Expression (3) can be improved as indicated by the following expression including  $\varphi_n$ , which is a term representing a phase difference between the spread code of the L1 C/A signal and the spread code of the LEX signal due to the error:

$$\varphi_{E6} = \left( \frac{\varphi_{L1}}{R_{L1}} + kT_{L1} \right) * R_{E6} + \psi_n \quad \dots (6)$$

where,

$\psi_n$ : a phase difference between the spread code of the L1 C/A signal and the spread code of the LEX signal predicted at the n-th time.

[0080]

Note that, when the several values are predicted as the error and the conversion is performed taking into account the respective values, the error may include the difference between the phase of the spread code of the L1 C/A signal and the phase of the spread code of the LEX signal due to the ionosphere delay error described above.

#### Embodiment 6

[0081]

Lastly, a signal generation circuit example in a satellite positioning system in an embodiment of the present invention is explained. Figure 7 is a generation circuit for a LEX signal used in the satellite positioning system according to the embodiment of the present invention.

[0082]

As an example, a signal generation circuit 700 relates to a LEX signal broadcasted in a 1278.75MHz band (E6 band) of the Quasi Zenith Satellite System (QZSS). The LEX signal is used as an augmentation signal.

The LEX signal is generated by a spread code generator 701, clock-controlled to alternately select, at an interval of 5.115 Mcps, a spread code of 2.5575 Mcps called "short code" CSK-code-modulated by a CSK modulator 702 by an 8-bit (= 256 kinds) message having 4 ms length and a spread code called "long code" of 410 ms length and 2.5575 Mcps superimposed on a square wave generated from a square wave generator 703, superimposed on a carrier wave frequency of 1278.75 MHz generated by a carrier wave generator 705, and transmitted.

Note that the CSK modulation is an abbreviation of code shift keying and is one of the modulation methods for changing a phase of a spread code according to a value of data.

[0083]

[Publicly-known technique and the like]

In relation to the present invention, contents of all theses and documents that are filed simultaneously with or before this specification and can be freely publicly acquired are incorporated as described contents of this specification by reference.

[0084]

[Combinations]

All of the constituent elements described in and/or all the steps of all of the methods or processing disclosed in this specification (including the claims, the embodiments, the abstract, and the drawings) can be combined in any combination excluding a combination in which these features are exclusive to one another.

[0085]

[Example of features]

The respective features described in this specification (including the claims, the embodiments, the abstract, and the drawings) can be, unless explicitly denied, replaced with alternative features that act for the same purpose, equivalent purposes, or similar purposes. Therefore, unless explicitly denied, the disclosed respective features are only an example of a comprehensive series of same or equivalent features.

[0086]

The present invention is limited to no specific configuration of the embodiments described above. The present invention can be expanded to the all new features or combinations of the new features, or the steps of all the new methods or processing, or the combinations of the steps described in this specification (including the claims, the embodiments, the abstract, and the drawings).

#### REFERENCE SIGNS LIST

[0087]

100 Satellite positioning system

101a to 101d Positioning satellites

102 Positioning receiving apparatus

1021 Reception antenna unit

1022 Front end unit

1023a, 1023b ADC units

1024 Data processing unit

## CLAIMS

1. A satellite positioning receiving apparatus of a satellite positioning system comprising one or more positioning satellites that transmit a first signal and a second signal having different frequencies, wherein

the satellite positioning receiving apparatus applies conversion processing to a frequency and phase information of the second signal on the basis of a frequency and phase information acquired when reception of the first signal is started or continuously performed.

2. The satellite positioning receiving apparatus according to claim 1, wherein the satellite positioning receiving apparatus decodes message information included in the second signal on the basis of the converted frequency and the converted phase information of the second signal.

3. The satellite positioning receiving apparatus according to claim 1, wherein the satellite positioning receiving apparatus continuously performs tracking of the second signal on the basis of the converted frequency and the converted phase information of the second signal.

4. The satellite positioning receiving apparatus according to any one of claims 1 to 3, wherein the satellite positioning receiving apparatus measures a distance between the positioning satellite and the satellite positioning receiving apparatus on the basis of the frequency and the phase information of the first signal or the converted frequency and the converted phase information of the second signal.

5. The satellite positioning receiving apparatus according to any one of claims 1 to 4, wherein the first signal is a C/A signal in an L1 frequency band (a 1575.42MHz band).

6. The satellite positioning receiving apparatus according to any one of claims 1 to 5, wherein the second signal is a LEX signal in an E6 frequency band (a 1278.75MHz band).
7. The satellite positioning receiving apparatus according to any one of claims 1 to 6, wherein, in the conversion processing of the frequency and the phase information of the second signal, the conversion processing is performed on the basis of an ionosphere delay error component caused by a difference between the frequency of the first signal and the frequency of the second signal.
8. The satellite positioning receiving apparatus according to any one of claims 1 to 7, wherein, in the conversion processing of the frequency and the phase information of the second signal, the conversion processing is performed after a plurality of candidates are set in the phase information of the second signal on the basis of errors included in the phase information of the first signal and the phase information of the second signal.
9. A satellite positioning signal receiving method in a satellite positioning system including a positioning satellite that transmits a first signal and a second signal having different frequencies and a satellite positioning receiving apparatus, wherein the satellite positioning receiving apparatus converts a frequency and phase information of the second signal on the basis of a frequency and phase information acquired when reception of the first signal is started or continuously performed.
10. The method according to claim 7, wherein message information included in the second signal is decoded on the basis of the converted frequency and the converted phase information of the second signal.

11. The method according to claim 7, wherein reception of the second signal is continuously performed on the basis of the converted frequency and the converted phase information of the second signal.
12. The method according to any one of claims 7 to 9, wherein a distance between the positioning satellite and the satellite positioning receiving apparatus is measured on the basis of the frequency and the phase information of the first signal or the converted frequency and the converted phase information of the second signal.
13. The method according to any one of claims 7 to 10, wherein the first signal is a C/A signal in an L1 frequency band (a 1575.42MHz band).
14. The method according to any one of claims 7 to 11, wherein the second signal is a LEX signal in an E6 frequency band (a 1278.75MHz band).