(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 450 170 B9

(12) **CORRECTED EUROPEAN PATENT SPECIFICATION**

(15) Correction information:
Corrected version no 1 (W1 B1)
Corrections, see
Description Paragraph(s) 23
Claims DE 1

(48) Corrigendum issued on:
09.09.2009 Bulletin 2009/37

(45) Date of publication and mention
of the grant of the patent:
18.02.2009 Bulletin 2009/08

(21) Application number: **02783648.5**

(22) Date of filing: **27.11.2002**

(51) Int Cl.:
G01R 23/12 $^{(2006.01)}$ ***G01R 25/00*** $^{(2006.01)}$
H04L 27/22 $^{(2006.01)}$

(86) International application number:
PCT/JP2002/012377

(87) International publication number:
WO 2003/046585 (05.06.2003 Gazette 2003/23)

---

(54) **PHASE DETECTOR CAPABLE OF DETECTING AN ACCUMULATED VALUE OF PHASE DISPLACEMENT AT A HIGH SPEED AND FREQUENCY STABILITY MEASUREMENT APPARATUS FOR ARBITRARY NOMINAL FREQUENCY USING THE SAME**

PHASENDETEKTOR, DER EINEN AKKUMULIERTEN WERT DER PHASENVERSCHIEBUNG MIT HOHER GESCHWINDIGKEIT ERKENNEN KANN, UND FREQUENZSTABILITÄTMESSVORRICHTUNG FÜR EINE BELIEBIGE NENNFREQUENZ DAMIT

DETECTEUR DE PHASE POUVANT DETECTER UNE VALEUR CUMULEE DE DECALAGE DE PHASE A UNE VITESSE ELEVEE ET APPAREIL DE MESURE DE LA STABILITE D'UNE FREQUENCE NOMINALE ARBITRAIRE

---

(84) Designated Contracting States:
DE GB

(30) Priority: **28.11.2001 JP 2001362504**

(43) Date of publication of application:
25.08.2004 Bulletin 2004/35

(73) Proprietor: **ANRITSU CORPORATION**
Atsugi-shi, Kanagawa 243-8555 (JP)

(72) Inventor: **UCHINO, Masaharu**
Aikawamachi, Aiko-gun, Kanagawa 243-0303 (JP)

(74) Representative: **Sajda, Wolf E. et al**
Meissner, Bolte & Partner GbR
Postfach 86 06 24
81633 München (DE)

(56) References cited:
JP-A- 11 098 432
JP-A- 2001 066 332
JP-A- 2001 264 370
US-B1- 6 310 925

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a phase detector and a frequency stability measuring apparatus using the same, and more particularly to a phase detector employing a technology for detecting the cumulative value of phase displacement determined by in-phase signal and quadrature signal between two signals at high speed in a simple configuration, and a frequency stability measuring apparatus applicable to an arbitrary nominal frequency using the same.

Background Art

[0002] For example, in a clock signal used in celestial observation or the like in the field of radio astronomy, only a slight fluctuation in its frequency results in a serious adverse effect on an observation result.

[0003] In such field, therefore, an atomic oscillator having an extremely high frequency stability of 10^{-13} or more per day (for example, 10^{-4} Hz or less per day in a signal of frequency of 1 GHz) is used as clock signal source.

[0004] To design and manufacture a clock signal source having such high frequency stability, it is necessary to measure the frequency stability of the signal source very precisely.

[0005] Generally, methods for measuring stability of signal frequency are known to include a method for measuring directly the frequency fluctuations of the signal to be measured by a frequency counter, and a method of measuring indirectly the frequency fluctuations of the signal to be measured by measuring the cumulative value of the phase displacement with respect to the reference signal.

[0006] This method for measuring the cumulative value of the phase displacement with respect to the reference signal is specifically described in "Elementary Digital Clock Technology" written by Masaya Kihara and Sadayasu Ono, 2001, published by Ohm-Sha (ISBN 4274035549), pp. 179 to 184.

[0007] That is, when measuring the cumulative value of phase displacement with respect to the reference signal, as shown in this publication, it is general to employ the beat system using the dual mixer and time interval counter.

[0008] In this beat system, while sharing the local oscillator, the reference signal Sr and object signal to be measured Sx are transformed into beat signal by the dual mixer, and the phase difference between the beat signals is to be measured by the time interval counter.

[0009] When detecting the phase displacement with respect to the reference signal, it is generally difficult to detect directly the phase displacement of the signals with high frequency.

[0010] Accordingly, as in this beat system, by preparing the reference signal Sr as the reference of measurement, equal in nominal frequency f to the object signal to be measured Sx and equal or higher in the frequency stability, the displacement of phase of the object signal to be measured Sx can be detected indirectly.

[0011] In such beat system, therefore, there is a problem that it is difficult to correspond to an arbitrary nominal frequency due to various reasons.

[0012] To solve this problem, a frequency stability measuring system is developed by a quadrature detection method applicable to an arbitrary nominal frequency.

[0013] That is, as shown in FIG. 11, in this frequency stability measuring system 10 by quadrature detection method, first, reference signal Sr and object signal to be measured Sx are transformed into reference signals Sr', Sx' in low frequency band by a frequency converter 1.

[0014] The reference signal Sr' and object signal to be measured Sx' transformed in the frequency converter 1 are put into a quadrature detector 2.

[0015] In the quadrature detector 2, an in-phase signal I representing an in-phase component between the entered two signals Sr', Sx', and a quadrature signal Q representing a quadrature component are determined, and put into a phase detector 3.

[0016] This phase detector 3 detects the variance $\Delta\phi$ of the phase determined by the entered in-phase signal I and quadrature signal Q, and accumulates the values of the variance $\Delta\phi$, and issues a cumulative value Φ of the phase displacement. Such phase detectors are known from the document JP-2001264370 A or from US-6,310,925 B.

[0017] The cumulative value Φ of the phase displacement expresses the frequency fluctuation of the object signal to be measured Sx from the reference signal, and therefore from this cumulative value Φ, it is possible to evaluate indirectly the frequency stability of the object signal to be measured Sx.

[0018] Thus, the frequency stability measuring system 10 by this quadrature detection method is applicable to any arbitrary nominal frequency, but the phase detector 3 used herein involves the following problems.

[0019] This phase detector 3 is configured specifically as shown in FIG. 12.

[0020] The phase detector 3 delays the complex number (I'+jQ') composed of in-phase signal I' and quadrature signal Q' entered at the previous clock timing by one clock period by a delay unit 4, and a conjugate complex number (I'-jQ') is determined by a conjugate converter 5.

[0021] This conjugate complex number (I'-jQ'), and a complex number (I+jQ) composed of in-phase signal I and quadrature signal Q entered at the next clock timing are multiplied at a next stage in a multiplication processor 6, and thereby II' + QQ' - j(IQ'-I'Q) is determined.

[0022] This multiplication processor 6 is actually composed of four multipliers for determining (II'), (QQ'), (IQ'), and (I'Q), and two adders for adding (or subtracting) them.

[0023] The result of multiplication process is expressed as $Aej\Delta\phi$ by using the base e of natural logarithm, phase displacement $\Delta\phi$, and positive number A, and is hence transformed into $\log A + j\Delta\phi$ by logarithmic transformation process at a next stage in a logarithmic converter 7.

[0024] Based on the calculation result in this logarithmic converter 7, the phase displacement $\Delta\phi$ of the imaginary part is extracted at a next stage by an imaginary part extractor 8.

[0025] The phase displacement $\Delta\phi$ extracted by the imaginary part extractor 8 is accumulated at a next stage by an accumulator 9.

[0026] That is, the accumulator 9 determines the cumulative value Φ corresponding to the frequency-fluctuations of the object signal to be measured Sx with respect to the reference signal Sr.

[0027] In the conventional phase detector 3, however, as mentioned above, four multipliers and two adders are needed for complex multiplication process of (I+jQ) and (I'-jQ'), and the configuration is complicated, and it takes much time in arithmetic process, and high speed operation is not realized.

Disclosure of Invention

[0028] It is hence an object of the present invention to solve the above problems, and present a phase detector capable of detecting phase displacement at high speed in a simple configuration.

[0029] It is another object of the present invention to provide a frequency stability measuring apparatus applicable to an arbitrary nominal frequency using the same phase detector.

[0030] In this case, as the frequency stability measuring apparatus of the present invention, it is the features thereof to use a digital phase detector, instead of a conventional time interval counter.

[0031] To achieve above objects, according to the first aspect of the present invention, there is provided a phase detector as defined in claim 1 and according to the second aspect of the present invention, there is provided a frequency stability measuring apparatus as defined in claim 4.

Brief Description of the Drawings

[0032]

FIG. 1 is a block diagram showing a configuration of a phase detector applied as a first embodiment of the present invention;
FIG. 2 is a diagram explaining the operation of essential parts of the phase detector in FIG. 1;
FIG. 3 is a diagram explaining the operation of essential parts of the phase detector in FIG. 1;
FIGS. 4A to 4F are diagrams explaining the operation of the essential parts of the phase detector in FIG. 1;
FIG. 5 is a diagram explaining the operation of the phase detector in FIG. 1;
FIG. 6 is a block diagram showing a configuration of a frequency stability measuring apparatus applied as a second embodiment of the present invention;
FIG. 7 is a diagram showing a configuration example of essential parts of the frequency stability measuring apparatus in FIG. 6;
FIG. 8 is a diagram showing a configuration example of essential parts of the frequency stability measuring apparatus in FIG. 6;
FIG. 9 is a diagram showing a configuration example of essential parts of the frequency stability measuring apparatus in FIG. 6;
FIG. 10 is a block diagram showing a configuration of a phase detector applied in the frequency stability measuring apparatus in FIG. 6;
FIG. 11 is a block diagram showing a configuration of a frequency stability measuring system in a prior art; and
FIG. 12 is a block diagram showing a configuration of a phase detector in a prior art.

Best Mode for Carrying Out the Invention

[0033] Preferred embodiments of phase detector and frequency stability measuring apparatus using the same of the present invention will be described below referring to the accompanying drawings.

(First embodiment)

[0034] Referring first to FIG. 1 to FIG. 4F, the phase detector applied as a first embodiment of the present invention is described below.

[0035] FIG. 1 is a block diagram showing a configuration of a phase detector 20 applied as the first embodiment of the present invention.

[0036] This phase detector 20 receives in-phase signal I showing in-phase component and quadrature signal Q showing quadrature component of a first signal and second signal respectively entered at every timing of sampling by way of an A/D converter of sampling clock type not shown, and determines the variation of phase of the second signal with respect to the phase of the first signal.

[0037] That is, the phase detector 20 sequentially receives the in-phase signal O showing the in-phase component and the quadrature signal Q showing the quadrature component between two signals, and determines the displacement of phase determined by the in-phase signal I and quadrature signal Q.

[0038] The phase detector 20 has, as described below, a phase region detector 21 which sequentially assigns angle region numbers to a plurality M of three or more of angle regions obtained by equally dividing an angle range of 2π preliminarily, on virtual quadrature coordinates expressing the in-phase signal I and quadrature signal Q, detects the angle region including the phase determined by the entered in-phase signal I and quadrature signal Q upon every input of the in-phase signal I and quadrature signal Q, and issues the angle region number of the detected angle region at every timing of each sampling clock.

[0039] That is, this phase region detector 21 equally divides the angle range of 2π into a plurality M of three or more of angle regions preliminarily on virtual quadrature coordinates expressing the in-phase signal I and quadrature signal Q, and assigns the angle region numbers sequentially in every angle region, and therefore it detects the angle region corresponding to the variation of the phase of the second signal starting from the phase of the first signal, and issues the angle region number assigned in the detected angle region.

[0040] The phase detector 20 also has a phase displacement detector 22 which determines the difference between the angle region number issued by the phase region detector 21 at the timing of a certain sampling clock and the angle region number issued at the timing of its preceding sampling clock, sequentially as information expressing the displacement amount and displacement direction of the phase.

[0041] That is, this phase displacement detector 22 issues a signal showing the time change of the variation amount of the phase from the change to the time of the angle region number issued from the phase region detector 21.

[0042] The phase detector 20 further has an out-of-bounds detector 25 which inspects whether or not the region number difference issued by the phase displacement detector 22 is within a predetermined range about the number M of the angle region, and issues data showing whether or not the phase is displaced to exceed the bounds of the angle region corresponding to the initial value of the region number assigned in the plurality of angle regions and the angle region corresponding to the final value.

[0043] That is, this out-of-bounds detector 25 receives the signal issued from the phase displacement detector 22, and issues an out-of-bounds signal including the out-of-bounds direction every time the variation amount of the phase exceeds a predetermined value on the virtual quadrature coordinates.

[0044] The phase detector 20 moreover has a phase rotation counter 26 which determines the number of rotations of the phase by accumulating the data issued by the out-of-bounds detector 26.

[0045] That is, this phase rotation counter 26 issues the number of rotations of the phase on the virtual quadrature coordinates by accumulating the out-of-bounds signals issued from the out-of-bounds detector 25.

[0046] The phase detector 20 still has a displacement accumulator 27 which determines the cumulative value of phase displacement determined by the in-phase signal I and quadrature signal Q, based on the region number issued by the phase region detector 21, the number M of angle regions, and the phase rotation count issued by the phase rotation counter 26.

[0047] That is, this displacement accumulator 27 determines the cumulative value of phase displacement determined by the in-phase signal I and quadrature signal Q, based on the angle region number issued by the phase region detector 21, the number of angle regions, and the number of rotations of the phase issued by the phase rotation counter 26.

[0048] The phase region detector 21 in the phase detector 20 having such configuration operates as shown in FIG. 2, by sequentially assigning angle region numbers 0, 1, ..., M-1 to a plurality M (in FIG. 2, M is an even number) of angle regions E(0), E(1), ... , E(M-1) obtained by equally dividing an angle range of absolute value of 2π (that is, $+2\pi$ or -2π or from $+\pi$ to $-\pi$) preliminarily, on virtual quadrature coordinates of I-axis and Q-axis mutually expressing the in-phase signal I and quadrature signal Q.

[0049] Further, the phase region detector 21 detects the angle region including the phase ϕ determined by the in-phase signal I and quadrature signal Q entered on the virtual quadrature coordinates, at every timing of the sampling clock of input of the in-phase signal I and quadrature signal Q, and issues the angle region number p_k assigned in the detected angle region.

[0050] The phase angle ϕ determined by the in-phase signal I and quadrature signal Q is calculated in the following formula:

$$\phi = \arg(I+jQ),$$

where arg(z) is a function expressing the argument of complex number z.

[0051] In this case, the number M of angle regions is the value for determining the precision of phase displacement precision, and the greater the number M of angle regions, the higher is the precision of phase displacement detection.

[0052] The number M of angle region is 3 or more, and actually it is a numerical value expressed, for example, from about 8 bits to tens of bits.

[0053] The angle region number p_k thus obtained in the phase region detector 21 is put into the phase displacement detector 22.

[0054] The phase displacement detector 22 is composed of a delay unit 23 for delaying the angle region number p_k issued from the phase region detector 21 by one sample (clock) each, and a subtractor 24 for determining the region number difference Δp_k by subtracting the angle region number p(k-1) issued from the delay unit 23 issued at the timing of a previous sampling clock, from the angle region number p_k issued from the phase region detector 21.

[0055] The phase displacement detector 22 determines this region number difference Δp_k sequentially as the information expressing the displacement amount and displacement direction of the phase, and sends out to the out-of-bounds detector 25.

[0056] The out-of-bounds detector 25 inspects the region number difference Δp_k issued from the phase displacement region 22 to identify with any one of three ranges predetermined as shown in FIG. 3 about the number M of angle regions mentioned above.

[0057] Consequently, the out-of-bounds detector 25 issues data s_k showing whether the phase is changed or not so as to exceed the bounds of the angle region E(0) corresponding to the initial value 0 and the angle region E(M-1) corresponding to the final value M-1 of the angle region numbers assigned in the plurality M of angle regions E(0), E (1), ... E(M-1).

[0058] That is, the out-of-bounds detector 25 receives a signal issued from the phase displacement detector 22, and issues an out-of-bounds signal s_k including the out-of-bounds direction every time the variation amount of the phase crosses the predetermined value on the virtual quadrature coordinates.

[0059] As shown in FIG. 3, there are two methods of setting the predetermined range in the case of an even number M of angle regions.

[0060] In a first range setting example (top in FIG. 3), the out-of-bounds detector 25 issues data $s_k = 1$ showing the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of -(M-1) to -([M/2]+1), with [M/2] being the maximum integer not exceeding M/2.

[0061] In this case, if the region number difference Δp_k is included in the range of -[M/2] to [M/2]-1, the out-of-bounds detector 25 issues data $s_k = 0$ showing that the phase is changed within a range not exceeding the bounds.

[0062] Or, in this case, if the region number difference Δp_k is included in the range of [M/2] to M-1, the out-of-bounds detector 25 issues data $s_k=-1$ showing that the phase is changed so as to exceed the bounds clockwise.

[0063] In a second range setting example in the case of an even number M of angle region (middle in FIG. 3), the out-of-bounds detector 25 issues data $s_k = 1$ showing the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of -(M-1) to -[M/2].

[0064] In this case, if the region number difference Δp_k is included in the range of -([M/2]-1) to [M/2], the out-of-bounds detector 25 issues data $s_k = 0$ showing that the phase is changed within a range not exceeding the bounds.

[0065] Or, in this case, if the region number difference Δp_k is included in the range of [M/2]+1 to M-1, the out-of-bounds detector 25 issues data $s_k=-1$ showing that the phase is changed so as to exceed the bounds clockwise.

[0066] As the predetermined range about the number M of angle regions, when the number M of angel regions is an odd number (bottom in FIG. 3), with [M/2] being the maximum integer not exceeding M/2, the out-of-bounds detector 25 issues data $s_k=1$ showing the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of -(M-1) to -([M/2]+1).

[0067] In this case, if the region number difference Δp_k is included in the range of -[M/2] to [M/2], the out-of-bounds detector 25 issues data $s_k=0$ showing that the phase is changed within a range not exceeding the bounds.

[0068] Further, in this case, if the region number difference Δp_k is included in the range of [M/2]+1 to M-1, the out-of-bounds detector 25 issues data $s_k=-1$ showing that the phase is changed so as to exceed the bounds clockwise.

[0069] The phase rotation counter 26 accumulates the data s_k issued from the out-of-bounds detector 25, and determines the number of times (phase rotation count) c_k of the phase rotating by 2 π portion.

[0070] The displacement accumulator 27 including a multiplier 28 and an adder 29 multiplies the phase rotation count

c_k issued from the phase rotation counter 26 and the number M of angle regions by the multiplier 28, and sums up the result of multiplication and the angle region number p_k issued from the phase region detector 21 by the adder 29, and determines the cumulative value u_k of the phase displacement determined by the in-phase signal I and quadrature signal Q.

[0071] The operation of the phase detector 20 having such configuration will be explained.

[0072] In the following explanation, for the sake of ease understanding of operation, the number M of angle regions is supposed to be 16.

[0073] In this phase detector 20, as shown in FIG. 4A, when sets of in-phase signal I and quadrature signal Q (I_0, Q_0), (I_1, Q_1), (I_2, Q_2), ... are sequentially entered at every timing of sampling clock by way of, for example, A/D converter or the like of sampling type not shown, the phase region detector 21 determines phases $\phi 0$, $\phi 1$, $\phi 2$, ... determined by these sets of in-phase signal I and quadrature signal Q.

[0074] The phase region detector 21 identifies these phases $\phi 0$, $\phi 1$, $\phi 2$, ... with any one of 16 angle regions E(0), E (1), ..., E(15) obtained by 16 equal divisions of 2 π as shown in FIG. 5, and issues angle region numbers p_0, p_1, p_2, ... corresponding to each angle region as shown in FIG. 4B.

[0075] Herein, if the phases $\phi 0$, $\phi 1$, $\phi 2$, ... are displaced counterclockwise from angle region E(2) to angle region E (8), angle region E(12), angle region E(14), angle region E(1), and angle region E(6), in this sequence as shown in FIG. 5, the angle region numbers issued from the phase region detector 21 are $p_0=2$, $p_1=8$, $p_2=12$, $p_3=14$, $p_4=1$, $p_5=6$, ... as shown in FIG. 4B.

[0076] In this case, the phase displacement detector 22 detects the region number difference Δp_k sequentially as follows as shown in FIG. 4C, and issues to the out-of-bounds detector 25.

$$\Delta p_0 = P_0 - 0 = 2$$

$$\Delta p_1 = P_1 - P_0 = 6$$

$$\Delta p_2 = P_2 - P_0 = 6$$

$$\Delta p_2 = P_2 - P_1 = 4$$

$$\Delta p_4 = P_4 - P_3 = -13$$

$$\Delta p_5 = P_5 - P_3 = 5$$

[0077] The out-of-bounds detector 25, in this embodiment, detects whether or not the phase has exceeded the bounds, by using the first range setting example when the number M of angle regions is an even number.

[0078] Also, the out-of-bounds detector 25, when receiving a region number difference Δp_k of -8 or more to 7 or less from the phase displacement detector 22, such as region number difference Δp_0, Δp_1, Δp_2, Δp_3, or Δp_5, issues detection data of 0 such as s_0, s_1, s_2, s_3, s_5, ... as shown in FIG. 4D.

[0079] Further, the out-of-bounds detector 25, when receiving a region number difference Δp_k of -9 or less from the phase displacement detector 22 such as region number difference $\Delta p4$, issues data s_4 of "1" showing the phase is changed to exceed counterclockwise the bounds of the angle region E(0) corresponding to the first region number 0 and the angle region E(15) corresponding to the final region number 15.

[0080] Although not shown, the out-of-bounds detector 25, when receiving an angle region number difference Δp_k of 8 or more from the phase displacement detector 22, issues data s_k of "-1" showing the phase is changed to exceed clockwise the bounds of the angle regions E(0), E(15).

[0081] The phase rotation counter 26 accumulates the data s_k issued from this out-of-bounds detector 25, and issues the number of rotations c_k of the phase as follows sequentially as shown in FIG. 4E.

$$c_0 = 0$$

$$c_1 = 0$$

$$c_2 = 0$$

$$c_3 = 0$$

$$c_4 = 1$$

$$c_5 = 1$$

[0082] The number of rotations c_k of the phase is input into the displacement accumulator 27 together with the angle region number p_k issued from the phase region detector 21, and is calculated sequentially as follows, and the cumulative values u_0, u_1, u_2, ... of the phase displacement are issued as shown in FIG. 4F.

$$u_0 = P_0 + C_0M = P_0 = 2$$

$$u_1 = P_1 + C_1M = P_1 = 8$$

$$u_2 = P_2 + C_2M = P_2 = 12$$

$$u_3 = P_3 + C_3M = P_3 = 14$$

$$u_4 = P_4 + C_4M = P_4 + M = 1 + 16 = 17$$

$$u_5 = P_5 + C_5M = P_5 + M = 6 + 16 = 22$$

[0083] Thus, the phase detector 20 of the embodiment, first, identifies the phase determined by the in-phase signal I and quadrature signal Q entered at the timing of a certain sampling clock with any one of three or more plurality M of angle regions E(0), E(1), ..., E(M-1) obtained by equally dividing the angle range of 2 π preliminarily, on virtual quadrature coordinates expressing the in-phase signal I and quadrature signal Q, and detects the angle region number assigned in this angle region.

[0084] Next, the phase detector 20 determines the difference Δp_k of the detected angle region number and the angle region number detected at the timing of the preceding sampling clock, and inspects whether or not the region number difference Δp_k is within the predetermined range about the number of regions M.

[0085] Herein, as the range predetermined about the number M of angle regions, the phase detector 20 determines the out-of-bounds data showing whether or not the phase is displaced over the bounds of the first angle region E(0) and final angle region E(M-1).

[0086] Accordingly, the phase detector 20 determines the cumulative value u_k of the phase displacement by calculation based on the number of rotations c_k obtained by accumulating the out-of-bounds data, the angle region number p_k, and the number M of angle regions.

[0087] Therefore, the phase detector 20 of the embodiment, as compared with the conventional method for determining the phase displacement by multiplication process of complex number of two sets of in-phase signal I and quadrature signal Q entered continuously, is smaller in the quantity of arithmetic process and is higher in operation speed.

(Second embodiment)

[0088] As a second embodiment of the present invention, this is to explain a frequency stability measuring apparatus for measuring the frequency stability of the object signal to be measured to be measured with respect to the reference signal, by using the phase detector having the above configuration.

[0089] FIG. 6 shows a configuration of a frequency stability measuring apparatus 40 applied as the second embodiment of the present invention.

[0090] In FIG. 6, a frequency converter 41 transforms reference a signal Sr and an object signal to be measured Sx equal in nominal frequency fa into a band below a specified frequency.

[0091] This frequency converter 41 is realized by using a mixer as shown in FIG. 7, by using a dividing circuit as shown in FIG. 8 or FIG. 9, or by using the both.

[0092] FIG. 7 is a structural example of two-mixer type frequency converter 41, in which a local oscillator circuit 42 oscillates a local oscillation signal Sc at a frequency fc different from the nominal frequency fa of the reference signal Sr and object signal to be measured Sx by tens of Hz to hundreds of kHz, and issues to mixers 43, 44.

[0093] Frequency component Sr' of difference from output component of the mixer 43 receiving the local oscillation signal Sc and reference signal Sr is extracted by a low pass filter (LPF) 45.

[0094] Similarly, frequency component Sx' of difference from output component of the mixer 44 receiving the local oscillation signal Sc and object signal to be measured Sx is extracted by an LPF 46.

[0095] As the frequency converter 41 using mixers, aside from the two-mixer type mentioned above, it is also possible to employ an image rejection type smaller in S/N drop due to an image although the structure is slightly complicated.

[0096] On the other hand, FIG. 8 shows a structural example of the frequency converter 41 using two frequency dividers, in which two frequency dividers 47, 48 are used, and the reference signal Sr and object signal to be measured Sx are divided in frequency by N, and divided signals Sr', Sx' are issued.

[0097] FIG. 9 shows an example of dividing by phase locked loop (PLL), in which a signal issued from a voltage control oscillator (VCO) 49 is multiplied by P times by a multiplier 50, the phase difference of the multiplied signal and reference signal Sr is detected by a phase comparator 51, the control signal extracted by an LPF 52 from this error signal is given to the VCO 49, and a signal Sr' locked at 1/P frequency of the reference signal Sr is issued from the VCO 49.

[0098] Further, an output signal from a VCO 53 is multiplied by P times by a multiplier 54, the phase difference of the multiplied signal and object signal to be measured Sx is detected by a phase comparator 55, the control signal extracted by an LPF 56 from this error signal is given to the VCO 53, and a signal Sx' locked at 1/P frequency of the object signal to be measured Sx is issued from the VCO 53.

[0099] Meanwhile, the entire frequency dividing ratio can be increased to NxP by using the frequency dividers 47, 48 in FIG. 8 in the front stage or rear stage of the frequency divider of PLL configuration in FIG. 9.

[0100] Further, in the front stage of the mixer type as shown in FIG. 7, the frequency dividing type in FIG. 8 or FIG. 9 or combination thereof may be provided.

[0101] However, in the signal dividing type in FIG. 8 or FIG. 9, the absolute displacement amount of phase is also compressed by the portion of frequency dividing ratio, but in the two-mixer type in FIG. 7, the absolute displacement amount of phase is not changed, and the two-mixer type in FIG. 7 is advantageous where precise measurement is needed.

[0102] The output of the two-mixer type frequency converter 41 includes phase variation component of the local oscillation signal Sc, but since this phase variation component is canceled in operation of a quadrature detector 65 described below, and there is no adverse effect on measurement.

[0103] Signals Sr', Sx' thus transformed to low frequency band in the frequency converter 41 are respectively put into a first A/D converter 60 and a second A/D converter 61.

[0104] The first A/D converter 60 and second A/D converter 61 sample the reference signal Sr' and object signal to be measured Sx' transformed into low frequency band by a common sampling signal Ss of frequency fs, convert into digital signals Dr, Dx, and send out into a first high pass filter (HPF) 62 and a second HPF 63.

[0105] The first HPF 62 removes the direct-current component contained in the output signal Dr of the first A/D converter 60, and the second HPF 63 removes the direct-current component contained in the output signal Dx of the second A/D converter 61.

[0106] As a result, it is effective to prevent occurrence of measurement error caused by direct-current offset of the frequency converter 41 and first and second A/D converters 60,61 and its fluctuations.

[0107] The first HPF 62 and second HPF 63 are of a primary CR type, and determine the average of input signals sequentially, and subtract the determined average from the input signal.

[0108] Next, the quadrature detector 65 determines the in-phase signal I showing the in-phase component and the quadrature signal Q showing the quadrature component of the signals Dr', Dx' issued from the first HPF 62 and second HPF 63.

[0109] In this quadrature detector 65, the output signal Dr' from the first HPF 62 is divided into two quadrature signal components Vr, Ur by a first 90-degree phase shifter 66, and put into an arithmetic circuit 68.

[0110] Further, the output signal Dx' from the second HPF 63 is divided into two quadrature signal components Vx, Ux by a second 90-degree phase shifter 67, and put into the arithmetic circuit 68.

[0111] With respect to these signal components, the arithmetic circuit 68 calculates as follows, and determines the in-phase signal Ik and quadrature signal Qk.

$$Ik = Vr \bullet Ur + Vx \bullet Ux$$

$$Qk = Ur \bullet Vx - Vr \bullet Ux$$

[0112] The first 90-degree phase shifter 66 and second 90-degree phase shifter 67 are composed of a half-band filter or Hilbert converter.

[0113] The in-phase signal Ik and quadrature signal Qk obtained in this manner are put into a phase detector 20' composed nearly same as the above phase detector 20.

[0114] As shown in FIG. 10, this phase detector 20' is similar to the phase detector 20, except for the structure of a displacement accumulator 27'.

[0115] The displacement accumulator 27' decimates the cumulative value u_k of phase displacement obtained from the angle region number p_k, number of rotations c_k of phase, and angle region number M, and issues the output to an evaluation calculator 80 described below.

[0116] In the evaluation calculator 80, as described below, the frequency stability is calculated, and it is hence required to decimate in order to extract only the low frequency component of the cumulative value u_k of phase displacement.

[0117] In this decimating process, treble cut-off process by LPF is needed as its pretreatment.

[0118] At this time, in the method for decimating after treble cut-off process by LPF of the cumulative value u_k of phase displacement issued by the displacement accumulator 27 of the phase detector 20 described above, the structure of the LPF is complicated.

[0119] In this method, the arithmetic processing for treble cut-off process must be executed on the data of bit length in the total of bit length of angle region number p_k and bit length of the number of rotations c_k of phase, and hence the structure of the LPF is complicated.

[0120] By contrast, in the displacement accumulator 27' of this phase detector 20', as shown in FIG. 10, first, treble cut-off process on the angle region number p_k is executed by the LPF 71, and then L/1 decimating process is executed on the output from the LPF 71 in the decimating unit 72, so that an angle region number p_k' is obtained.

[0121] Further, after treble cut-off process on the number of rotations c_k of phase in the LPF 73, the output from the LPF 73 is decimated by L/1 in the decimating unit 74, and the number of rotations c_k' of phase is obtained.

[0122] The processing result c_k' and number M of angle regions are multiplied in the multiplier 28.

[0123] Then, the output from the multiplier 28 and the processing result p_k' of the decimating unit 72 are summed up in the adder 29, and the phase displacement amount u_k' decimated from the adder 29 is issued to the evaluation calculator 80.

[0124] That is, in the displacement accumulator 27' of the phase detector 20', the decimating process on the angle region number p_k and the number of rotations c_k of phase is executed separately, and the cumulative value u_k' of phase displacement is calculated.

[0125] As a result, the number of input bits of the LPF can be decreased, and the individual calculation processing of the LPF is heightened in speed.

[0126] The cumulative value u_k' of phase displacement detected by the phase detector 20' is put into the evaluation calculator 80, and is used for evaluation calculation for evaluation of frequency stability of the object signal to be measured Sx with respect to the reference signal Sr.

[0127] Functions used in this evaluation calculation include ADEV (Allan deviation) used in Wanda evaluation, MADED (modified Allan deviation), TDEV (time deviation), TIE (time interval error), MTIE (maximum time interval error), and others.

[0128] By calculating any one of these functions by using the cumulative value u_k' detected by the phase detector 20' as variable, the frequency stability of object signal to be measured Sx with respect to the reference signal Sr can be evaluated.

[0129] For example, in the case of evaluation by ADEV, the following calculation is executed on the cumulative value u_k'=Xk of phase displacement.

$$\mathrm{ADEV}(n/f) = \{\Sigma\{x[t_0 + (i + 2n)/f] - 2x[t_0 + (i + n)/f] + x(t_0 + i/f)\}^2 /[2n^2(N - 2n)/f^2]\}^{1/2}$$

where symbol Σ is the sum from i=1 to N-2n, N is the total number of samples, f is the sampling frequency on variable Xk, and t0 is the time initial value.

[0130] In the case of evaluation by MADEV, the calculation is as follows.

$$\mathrm{MADEV}(n/f) = \{j\Sigma\{i\Sigma x[t_0 + (i + 2n)/f] - 2x[t_0 + (i + n)/f] + x(t_0 + i/f)\}^2 /[2n^4(N - 3n + 1)/f^2]\}^{1/2}$$

where symbol iΣ is the sum from I=j to n+j-1, and jΣ is the sum from j=1 to N-3n+1.

[0131] In the case of evaluation by TDEV, the calculation is as follows.

$$\mathrm{TDEV}(n/f) = \{j\Sigma\{i\Sigma x[t_0 + (i + 2n)/f] - 2x[t_0 + (i + n)/f] + x(t_0 + i/f)\}^2 /[6n^6(N - 3n + 1)]\}^{1/2}$$

[0132] The result of calculation by the evaluation calculator 80 is issued to the output device such as display unit or printer not shown, and from this output, therefore, the frequency stability of object signal to be measured Sx with respect to the reference signal Sr can be evaluated.

[0133] As explained herein, the phase detector of the present invention identifies the phase determined by the in-phase signal I and quadrature signal Q entered at a certain timing with any one of a plurality M of three or more of angle regions obtained by equally dividing an angle range of 2 n, on virtual quadrature coordinates expressing the in-phase signal I and quadrature signal Q, detects the angle region number assigned in this angle region, determines the difference between the detected angle region number and the angle region number determined at its preceding timing, inspects the region number difference to find in any one of the ranges predetermined for the number M of angle regions, issues the data showing whether or not the phase is displaced beyond the bounds of the initial angle region and final angle region, and determines the cumulative value of phase displacement from the number of rotations of phase obtained by accumulating such data, the region number, and the number M of angler regions.

[0134] Accordingly, the phase detector of the present invention is smaller in the arithmetic process and higher in operation speed, as compared with the conventional phase detector designed to detect phase displacement by processing multiplication of complex number composed of two sets of in-phase signal I and quadrature signal Q entered continuously.

[0135] The frequency stability measuring apparatus of the present invention transforms the reference signal and object signal to be measured to low frequency band by a frequency converter, converts them into digital values by an A/D converter, and removes the direct-current components of the converted digital signals by the first and second HPF, detects quadrature signals by a quadrature detector, determines the in-phase signal and quadrature signal of the reference signal and object signal to be measured, determines the cumulative value of the phase displacement by the phase detector, and evaluates the cumulative value.

[0136] Accordingly, the frequency stability measuring apparatus of the present invention is free from direct-current offset of a frequency converter or an A/D converter or an error due to its fluctuation, and is hence capable of measuring at high precision in a simple configuration.

[0137] Further, the frequency stability measuring apparatus of the present invention is, when decimating as pretreatment for evaluating in the displacement accumulator, designed to execute independently the decimating process of region numbers issued by the phase region detector and the decimating process of the number of rotations of phase, and then determine the cumulative value of phase displacement, and therefore the configuration of the LPF used in decimating process can be simplified.

[0138] In the frequency stability measuring apparatus of the present invention, when using two-mixer type frequency converter as a frequency converter, phase fluctuations due to frequency fluctuations are not compressed, and the phase fluctuations of local oscillation signals are canceled to each other to have no adverse effects on measurement, so that measurement of high precision is realized.

Claims

1. A phase detector for receiving an in-phase signal I representing an in-phase component and a quadrature signal Q representing a quadrature component of a first signal and a second signal, respectively, and for determining a variation of the phase of the second signal with respect to the phase of the first signal, comprising:

- a phase region detector (21) which is adapted to divide an angle range of 2 π preliminarily, on virtual quadrature coordinates expressing the in-phase signal I and the quadrature signal Q, into a plurality M of three or more angle regions, to sequentially assign angle region numbers in each of the angle regions, to detect the angle region corresponding to the variation of phase of the second signal starting from the phase of the first signal, and to issue the angle region number assigned in the detected angle region;
- a phase displacement detector (22) which is adapted to issue a signal expressing the time change of the variation of the phase from the change corresponding to the time of the angle region number issued from the phase region detector (21);
- an out-of-bounds detector (25) which is adapted to receive a signal issued from the phase displacement detector (22), and to issue an out-of-bounds signal including the out-of-bounds direction every time the variation amount of the phase exceeds a predetermined value on the virtual quadrature coordinates;
- a phase rotation counter (26) which is adapted to issue the number of rotations of the phase on the virtual quadrature coordinates by accumulating the out-of-bounds signals issued from the out-of-bounds detector (25); and
- a displacement accumulator (27) which is adapted to determine the cumulative value of phase displacement determined by the in-phase signal I and the quadrature signal Q, based on the angle region number issued by the phase region detector (21), the number of angle regions, and the number of rotations of the phase issued by the phase rotation counter (26), wherein the phase region detector (21) is adapted to detect the angle region including the phase Φ determined by the in-phase signal I and the quadrature signal Q entered on the virtual quadrature coordinates, at every input timing of the in-phase signal I and the quadrature signal Q, and to issue an angle region number p_k assigned in the detected angle region;
- wherein the phase displacement detector (22) is composed of a delay unit (23) for delaying the angle region number p_k issued from the phase region detector (21) at a certain timing by one sample clock each, and a subtractor (24) for determining a region number difference Δp_k by subtracting an angle region number $p_{(k-1)}$ issued from the delay unit (23) being issued from the phase region detector (21) at the preceding timing, from the angle region number p_k issued from the phase region detector (21);
- wherein the out-of-bounds detector (25) is adapted to receive a signal issued from the phase displacement detector (22), and to issue an out-of bounds signal including the out-of-bounds direction every time the variation amount of the phase exceeds a predetermined value on the virtual quadrature coordinates; and
- wherein the out-of-bounds detector (25) is adapted to identify the region number difference issued from the phase displacement detector (22) with any one of the ranges predetermined for the number M of angle regions, and to issue data s_k representing whether or not the phase has been displaced to exceed the bounds of the angle region corresponding to the initial value and the angle region corresponding to the final value of the angle region numbers assigned in the plurality of angle regions,

characterized in that the out-of-bounds detector (25) is adapted to, when the number M of angle regions is an even number as the predetermined range, in the case of [M/2] being the maximum integer not exceeding M/2,
- issue data $s_k = 1$ representing that the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of - (M - 1) to - ([M/2] + 1),

- issue data $s_k = 0$ representing that the phase is changed within a range not exceeding the bounds when the region number difference Δp_k is included in the range of - [M/2] to [M/2] - 1, and
- issue data $s_k = -1$ representing that the phase is changed so as to exceed the bounds clockwise when the region number difference Δp_k is included in the range of [M/2] to M - 1;

or **in that** the out-of-bounds detector (25) is adapted to, when the number M of angle regions is an even number as the predetermined range, in the case of [M/2] being the maximum integer not exceeding M/2,

- issue data $s_k = 1$ representing that the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of - (M - 1) to - [M/2],
- issue data $s_k = 0$ representing that the phase is changed within a range not exceeding the bounds when the region number difference Δp_k is included in the range of - ([M/2] - 1) to [M/2], and
- issue data $s_k = -1$ representing that the phase is changed so as to exceed the bounds clockwise when the region number difference Δp_k is included in the range of [M/2] + 1 to M - 1;

or **in that** the out-of-bounds detector (25) is adapted to, when the number M of angle regions is an odd number as the predetermined range, in the case of [M/2] being the maximum integer not exceeding M/2,

- issue data $s_k = 1$ representing that the phase is changed to exceed the bounds counterclockwise when the region number difference Δp_k is included in the range of - (M-1) to - ([M/2] + 1),
- issue data $s_k = 0$ representing that the phase is changed within a range not exceeding the bounds when the region number difference Δp_k is included in the range of - [M/2] to [M/2], and
- issue data $s_k = -1$ representing that the phase is changed so as to exceed the bounds clockwise when the region number difference Δp_k is included in the range of [M/2] + 1 to M - 1.

2. The phase detector according to claim 1,
characterized in that the phase rotation counter (26) is adapted to accumulate the data s_k issued from the out-of-bounds detector (25), and to determine the number of times, i.e. phase rotation count, c_k of the phase rotating by 2π portion.

3. The phase detector according to claim 2,
characterized in that the displacement accumulator (27) includes a multiplier (28) and an adder (29), and is adapted to multiply the phase rotation count c_k issued from the phase rotation counter (26) and the number M of angle regions by the multiplier (28), and to sum up the result of multiplication and the angle region number p_k issued from the phase region detector (21) by the adder (29), and to determine the cumulative value u_k of the phase displacement determined by the in-phase signal I and the quadrature signal Q.

4. A frequency stability measuring apparatus using a phase detector, comprising:

- a frequency converter (41) which is adapted to convert a reference signal and an object signal to be measured equal in nominal frequency into a band below a specified frequency,
- first and second A/D converters (60, 61) which are adapted to convert the reference signal and the object signal to be measured, that are transformed by the frequency converter (41), into digital values by sampling by a common sampling signal,
- first and second high pass filters (62, 63) which are adapted to remove direct-current components of output signals from the first and second A/D converters (60, 61),
- a quadrature detector (65) which is adapted to detect an in-phase signal representing its in-phase component and a quadrature signal representing its quadrature component, by detecting quadrature components of output signals from the first and second high pass filters (62, 63),
- a phase detector (20’) which is adapted to detect the variation of the phase determined by the in-phase signal and the quadrature signal issued from the quadrature detector (65), and
- an evaluation calculator (80) which is adapted to calculate in order to evaluate a relative frequency stability of an object signal to be measured, with respect to a reference signal by using the phase variation detected by the phase detector (20’),

wherein the phase detector (20’) is a phase detector according to any one of claims 1 to 3.

Patentansprüche

1. Phasendetektor zum Empfangen eines gleichphasigen Signals I, das eine gleichphasige Komponente repräsentiert, und eines Quadratursignals Q, das eine Quadraturkomponente repräsentiert, von einem ersten Signal bzw. von einem zweiten Signal, sowie zum Bestimmen einer Änderung der Phase des zweiten Signals in bezug auf die Phase des ersten Signals, wobei der Phasendetektor folgendes aufweist:

- einen Phasenbereichsdetektor (21), der dazu ausgebildet ist, einen Winkelbereich von 2 π an virtuellen Quadraturkoordinaten, die das gleichphasige Signal I und das Quadratursignal zum Ausdruck bringen, vorab in eine Vielzahl M von drei oder mehr Winkelbereichen zu teilen, um Winkelbereichszahlen in jedem der Winkelbereiche nacheinander zuzuordnen, um den der Phasenänderung des zweiten Signals entsprechenden Winkelbereich ausgehend von der Phase des ersten Signals zu detektieren und um die in dem detektierten Winkelbereich zugeordnete Winkelbereichszahl abzugeben;
- einen Phasenverschiebungsdetektor (22), der zum Abgeben eines Signals ausgebildet ist, das die zeitliche Veränderung der Phasenänderung von der Änderung zum Ausdruck bringt, und zwar entsprechend dem Zeitpunkt der Abgabe der Winkelbereichszahl von dem Phasenbereichsdetektor (21);
- einen Ausbereichs-Detektor (25), der dazu ausgebildet ist, ein von dem Phasenverschiebungsdetektor (22) abgegebenes Signal zu empfangen sowie ein Ausbereichs-Signal, das die Ausbereichs-Richtung beinhaltet, jeweils dann abzugeben, wenn der Änderungsbetrag der Phase einen vorbestimmten Wert bei den virtuellen Quadraturkoordinaten übersteigt;
- einen Phasenrotationszähler (26), der dazu ausgebildet ist, die Anzahl von Rotationen der Phase bei den virtuellen Quadraturkoordinaten durch Akkumulieren der von dem Ausbereichs-Detektor (25) abgegebenen Ausbereichs-Signale abzugeben; und
- einen Verschiebungs-Akkumulierer (27), der dazu ausgebildet ist, den kumulativen Wert der Phasenverschiebung, die durch das gleichphasige Signal I und das Quadratursignal Q bestimmt wird, auf der Basis der von dem Phasenbereichsdetektor (21) abgegeben Winkelbereichszahl, der Anzahl der Winkelbereiche sowie der von dem Phasenrotationszähler (26) abgegebenen Anzahl von Rotationen der Phase zu bestimmen, wobei der Phasenbereichsdetektor (21) dazu ausgebildet ist, den Winkelbereich zu detektieren, der die Phase Φ beinhaltet, die durch das gleichphasige Signal I und das Quadratursignal Q bestimmt wird, welche an den virtuellen Quadraturkoordinaten eingegeben werden, und zwar bei jedem Eingabezeitpunkt des gleichphasigen Signals I und des Quadratsignals Q, und ferner dazu ausgebildet ist, eine in dem detektierten Winkelbereich zugeordnete Winkelbereichszahl p_k abzugeben;
- wobei der Phasenverschiebungsdetektor (22) gebildet ist aus einer Verzögerungseinheit (23) zum Verzögern der von dem Phasenbereichsdetektor (21) abgegebenen Winkelbereichszahl p_k zu einem bestimmten Zeitpunkt um jeweils einen Abtastimpuls, sowie aus einem Subtrahierer (24) zum Bestimmen einer Bereichszahldifferenz Δp_k durch Subtrahieren einer von der Verzögerungseinheit (23) abgegebenen Winkelbereichszahl $p_{(k-1)}$, die von dem Phasenbereichsdetektor (21) zu dem vorausgehenden Zeitpunkt abgegeben worden ist, von der von dem Phasenbereichsdetektor (21) abgegebenen Winkelbereichszahl p_k;
- wobei der Ausbereichs-Detektor (25) dazu ausgebildet ist, ein von dem Phasenverschiebungsdetektor (22) abgegebenes Signal zu empfangen und ein Ausbereichs-Signal, das die Ausbereichs-Richtung beinhaltet, jedes Mal dann abzugeben, wenn der Änderungsbetrag des Phase einen vorbestimmten Wert bei den virtuellen Quadraturkoordinaten übersteigt; und
- wobei der Ausbereichs-Detektor (25) dazu ausgebildet ist, die Bereichszahldifferenz zu identifizieren, die von dem Phasenverschiebungsdetektor (22) bei einem beliebigen der für die Anzahl M von Winkelbereichen vorbestimmten Bereiche abgegeben wird, sowie Daten s_k abzugeben, welche angeben, ob die Phase derart verschoben worden ist oder nicht, daß dies die Grenzen des Winkelbereichs übersteigt, die dem Anfangswert entsprechen, sowie die Grenzen des Winkelbereichs übersteigt, die dem abschließenden Wert der Winkelbereichszahlen entsprechen, die in der Vielzahl von Winkelbereichen zugeordnet sind,

dadurch gekennzeichnet,

daß dann, wenn als vorbestimmter Bereich die Anzahl M von Winkelbereichen eine gerade Zahl ist und in dem Fall, daß [M/2] die maximale ganze Zahl ist, die M/2 nicht übersteigt, der Ausbereichs-Detektor (25) dazu ausgebildet ist,

- Daten s_k = 1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Gegenuhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - (M-1) bis - ([M/2] + 1) enthalten ist,
- Daten s_k = 0 abzugeben, die anzeigen, daß die Phase innerhalb eines Bereichs verändert ist, der die Grenzen nicht überschreitet, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - [M/2] bis [M/2] -1 enthalten ist, und
- Daten s_k = -1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Uhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von [M/2] bis M - 1 enthalten ist;

oder daß dann, wenn als vorbestimmter Bereich die Anzahl M von Winkelbereichen eine gerade Zahl ist und in dem Fall, daß [M/2] die maximale ganze Zahl ist, die M/2 nicht übersteigt, der Ausbereichs-Detektor (25) dazu ausgebildet ist,

- Daten s_k = 1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Gegenuhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - (M-1) bis - ([M/2] enthalten ist,
- Daten s_k = 0 abzugeben, die anzeigen, daß die Phase innerhalb eines Bereichs verändert ist, der die Grenzen nicht überschreitet, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - ([M/2] -1) bis [M/2] enthalten ist, und
- Daten s_k = -1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Uhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von [M/2] + 1 bis M - 1 enthalten ist;

oder daß dann, wenn als vorbestimmter Bereich die Anzahl M von Winkelbereichen eine ungerade Zahl ist und in dem Fall, daß [M/2] die maximale ganze Zahl ist, die M/2 nicht übersteigt, der Ausbereichs-Detektor (25) dazu ausgebildet ist,

- Daten s_k = 1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Gegenuhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - (M-1) bis - ([M/2] +1) enthalten ist,
- Daten s_k = 0 abzugeben, die anzeigen, daß die Phase innerhalb eines Bereichs verändert ist, der die Grenzen nicht überschreitet, wenn die Bereichszahldifferenz Δp_k in dem Bereich von - [M/2] bis [M/2] enthalten ist, und
- Daten s_k = -1 abzugeben, die anzeigen, daß die Phase derart verändert ist, daß die Grenzen im Uhrzeigersinn überschritten sind, wenn die Bereichszahldifferenz Δp_k in dem Bereich von [M/2] + 1 bis M - 1 enthalten ist.

2. Phasendetektor nach Anspruch 1,
dadurch gekennzeichnet,
daß der Phasenrotationszähler (26) dazu ausgebildet ist, die von dem Ausbereichs-Detektor (25) abgegebenen Daten s_k zu akkumulieren sowie die Anzahl von Malen, d.h. den Phasenrotations-Zählstand c_k der um den Bereich von 2π rotierenden Phase zu bestimmen.

3. Phasendetektor nach Anspruch 2,
dadurch gekennzeichnet,
daß der Verschiebungs-Akkumulierer (27) einen Multiplizierer (28) und einen Addierer (29) aufweist und dazu ausgebildet ist, den von dem Phasenrotationszähler (26) abgegebenen Phasenrotations-Zählstand c_k und die Anzahl M von Winkelbereichen mittels des Multiplizierers (28) zu multiplizieren sowie das Resultat der Multiplikation und die von dem Phasenbereichsdetektor (21) abgegebene Phasenbereichszahl p_k mittels des Addierers (29) zu addieren sowie den kumulativen Wert u_k der durch das gleichphasige Signal I und das Quadratursignal Q bestimmten Phasenverschiebung zu bestimmen.

4. Frequenzstabilitäts-Meßvorrichtung, die von einem Phasendetektor Gebrauch macht, wobei die Meßvorrichtung folgendes aufweist:

- einen Frequenzwandler (41), der dazu ausgebildet ist, ein Referenzsignal und ein Objektsignal, die hinsichtlich der Nominalfrequenz gleich zu messen sind, in ein Band unterhalb einer vorgegebenen Frequenz umzuwandeln,
- einen ersten und einen zweiten A/D-Wandler (60, 61), die dazu ausgebildet sind, das Referenzsignal und das Objektsignal, die zu messen sind und die von dem Frequenzwandler (41) umgewandelt worden sind, in digitale Werte umzuwandeln, indem sie mit einem gemeinsamen Abtastsignal abgetastet werden,
- ein erstes und ein zweites Hochpaßfilter (62, 63), die dazu ausgebildet sind, Gleichstromkomponenten aus Ausgangssignalen von dem ersten und dem zweiten A/D-Wandler (60, 61) zu entfernen,
- einen Quadraturdetektor (65), der dazu ausgebildet ist, ein gleichphasiges Signal unter Darstellung von seiner gleichphasigen Komponente sowie ein Quadratursignal unter Darstellung von seiner Quadraturkomponente durch Detektieren von Quadraturkomponenten von Ausgangssignalen von dem ersten und dem zweiten Hochpaßfilter (62, 63) zu detektieren,
- einen Phasendetektor (20'), der dazu ausgebildet ist, die Änderung der Phase zu detektieren, die durch das gleichphasige Signal und das Quadratursignal bestimmt worden ist, die von dem Quadraturdetektor (65) abgegeben worden sind, und
- eine Auswertungs-Recheneinrichtung (80), die dazu ausgebildet ist, einen Rechenvorgang auszuführen, um eine relative Frequenzstabilität eines zu messenden Objektsignals in bezug auf ein Referenzsignal unter Verwendung der durch den Phasendetektor (20') detektierten Phasenänderung auszuwerten,

wobei es sich bei dem Phasendetektor (20') um einen Phasendetektor nach einem der Ansprüche 1 bis 3 handelt.

Revendications

1. Détecteur de phase pour recevoir un signal en phase I représentant une composante en phase et un signal en quadrature Q représentant une composante en quadrature d'un premier signal et d'un second signal, respectivement, et pour déterminer une variation de la phase du second signal par rapport à la phase du premier signal, comprenant:

   - un détecteur de région de phase (21) qui est adapté à diviser une plage angulaire de 2π de manière préliminaire, sur des coordonnées de quadrature virtuelle exprimant le signal en phase I et le signal en quadrature Q, en une pluralité M de régions angulaires, M étant égal à 3 ou plus, à attribuer en séquence des numéros de régions angulaires dans chacune des régions angulaires, à détecter la région angulaire correspondant à la variation de phase du second signal en partant de la phase du premier signal, et à fournir le numéro de région angulaire attribué dans la région angulaire détectée;
   - un détecteur de déplacement de phase (22) qui est adapté à délivrer un signal exprimant le changement temporel de la variation de la phase à partir du changement correspondant au temps du numéro de région angulaire délivré par le détecteur de région de phase (21);
   - un détecteur hors-limites (25) qui est adapté à recevoir un signal délivré par le détecteur de déplacement de phase (22), et à délivrer un signal hors-limites incluant la direction hors-limites chaque fois que la variation quantitative de la phase excède une valeur prédéterminée sur les coordonnées de quadrature virtuelle;
   - un compteur de rotation de phase (26) qui est adapté à délivrer le nombre de rotations de la phase sur les coordonnées de quadrature virtuelle en accumulant les signaux hors-limites délivrés par le détecteur hors-limites (25); et
   - un accumulateur de déplacement (27) qui est adapté à déterminer la valeur cumulative du déplacement de phase déterminé par le signal en phase I et le signal en quadrature Q, en se basant sur le numéro de région angulaire délivré par le détecteur de région de phase (21), le nombre de régions angulaires, et le nombre de rotations de la phase délivré par le compteur de rotations de phase (26), le détecteur de région de phase (21) étant adapté à détecter la région angulaire qui inclut la phase Φ déterminée par le signal en phase I et par le signal en quadrature Q entrés sur les coordonnées de quadrature virtuelle, à tout instant d'entrée du signal en phase I et du signal en quadrature Q, et à délivrer un numéro de région angulaire p_k attribué dans la région angulaire détectée;
   - dans lequel le détecteur de déplacement de phase (22) est composé d'une unité à retard (23) pour retarder le numéro de région angulaire p_k délivré par le détecteur de région de phase (21) à une certaine temporisation à raison d'un signal échantillon d'horloge à chaque fois, et d'un soustracteur (24) pour déterminer une différence de numéro de région Δp_k en soustrayant un numéro de région angulaire $p_{(k-1)}$ délivré par l'unité à retard (23), lequel est délivré par le détecteur de région de phase (21) lors de la temporisation précédente, depuis le numéro de région angulaire p_k délivré par le détecteur de région de phase (21);
   - dans lequel le détecteur hors-limites (25) est adapté à recevoir un signal délivré par le détecteur de déplacement de phase (22), et à délivrer un signal hors-limites qui inclut la direction hors-limites chaque fois que la variation quantitative de la phase excède une valeur prédéterminée sur les coordonnées de quadrature virtuelle; et

   dans lequel le détecteur hors-limites (25) est adapté à identifier la différence de numéro de région délivrée par le détecteur de déplacement de phase (22) avec l'une quelconque des plages prédéterminées pour le nombre M de régions angulaires, et à délivrer des données s_k qui représentent si la phase a été ou non déplacée pour excéder les limites de la région angulaire correspondant à la valeur initiale et la région angulaire correspondant à la valeur finale des numéros de région angulaire attribués dans la pluralité de régions angulaires, **caractérisé en ce que** le détecteur hors-limites (25) est adapté, quand le nombre M de régions angulaires est un nombre pair à titre de plages prédéterminées, dans le cas où [M/2] est l'entier maximum qui ne dépasse pas M/2:

   - à délivrer des données $s_k = 1$ représentant que la phase est changée pour dépasser les limites dans le sens inverse aux aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de -(M-1) à -([M/2]+1),
   - à délivrer des données $s_k = 0$ représentant que la phase est changée dans une plage qui ne dépasse pas les limites quand la différence de numéro de région Δp_k est incluse dans la plage de -[M/2] à [M/2]-1, et
   - à délivrer des données $s_k = -1$ représentant que la phase est changée de manière à dépasser les limites dans le sens des aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de [M/2] à M-1 ; ou **en ce que** le détecteur hors limites (25) est adapté, quand le nombre M de régions angulaires est un nombre pair à titre de plage prédéterminée, dans le cas où [M/2] est l'entier maximum qui ne dépasse pas M/2,
   - à délivrer des données $s_k = 1$ représentant que la phase est changée pour dépasser les limites dans le sens inverse aux aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de -(M-1) à -[M/2],

- à délivrer des données $s_k = 0$ représentant que la phase est changée dans une plage qui ne dépasse pas les limites quand la différence de numéro de région Δp_k est incluse dans la plage de -([M/2]-1) à [M/2], et
- à délivrer des données $s_k = -1$ représentant que la phase est changée de façon à dépasser les limites dans le sens des aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de [M/2]+1 à M-1 ;

ou **en ce que** le détecteur hors limites (25) est adapté, quand le nombre M de régions angulaires est un nombre impair à titre de plage prédéterminée, dans le cas où [M/2] est l'entier maximum qui ne dépasse pas M/2,

- à délivrer des données $s_k = 1$ représentant que la phase est changée pour dépasser les limites dans le sens inverse aux aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de -(M-1) à - ([M/2]+1),
- à délivrer des données $s_k = 0$ représentant que la phase est changée dans une plage qui ne dépasse pas les limites quand la différence de numéro de région Δp_k est incluse dans la plage de -[M/2] à [M/2], et
- à délivrer des données $s_k = -1$ représentant que la phase est changée de manière à dépasser les limites dans le sens des aiguilles d'une montre quand la différence de numéro de région Δp_k est incluse dans la plage de [M/2]+1 à M-1.

2. Détecteur de phase selon la revendication 1,
caractérisé en ce que le compteur de rotations de phase (26) est adapté à accumuler les données s_k délivrées par le détecteur hors-limites (25), et à déterminer le nombre de fois, c'est-à-dire le décompte de rotations de phase, c_k où la phase tourne par pas de 2π.

3. Détecteur de phase selon la revendication 2,
caractérisé en ce que l'accumulateur de déplacement (27) inclut un multiplicateur (28) et un opérateur d'addition (29), et est adapté à multiplier le décompte de rotations de phase c_k délivré par le compteur de rotations de phase (26) et le nombre M de régions angulaires par le multiplicateur (28) et à faire une somme du résultat de la multiplication et du numéro de région angulaire p_k délivré par le détecteur de région de phase (21) par l'opérateur d'addition (29), et à déterminer la valeur cumulative u_k du déplacement de phase déterminé par le signal en phase I et par le signal en quadrature Q.

4. Appareil de mesure de stabilité de fréquence utilisant un détecteur de phase, comprenant:

- un convertisseur de fréquence (41) qui est adapté à convertir un signal de référence et un signal objet à mesurer dont la fréquence nominale est égale, dans une bande au-dessous d'une fréquence spécifiée,
- un premier et un second convertisseur analogique/numérique (60, 61) qui sont adaptés à convertir le signal de référence et le signal objet à mesurer, qui sont transformés par le convertisseur de fréquence (41), en valeur numérique par échantillonnage par un signal d'échantillonnage commun,
- un premier et un second filtre passe-haut (62, 63) qui sont adaptés à supprimer des composantes à courant continu hors des signaux de sortie provenant du premier et du second convertisseur A/N (60, 61),
- un détecteur de quadrature (65) qui est adapté à détecter un signal en phase représentant sa composante en phase et un signal en quadrature représentant sa composante en quadrature, par détection des composantes en quadrature de signaux de sortie provenant du premier et du second filtre passe-haut (62, 63),
- un détecteur de phase (20') qui est adapté à détecter la variation de la phase déterminée par le signal en phase et par le signal en quadrature délivré par le détecteur de quadrature (65), et
- un calculateur d'évaluation (80) qui est adapté à calculer afin d'évaluer une stabilité de fréquence relative d'un signal objet à mesurer par rapport à un signal de référence en utilisant la variation de phase détectée par le détecteur de phase (20'),

dans lequel le détecteur de phase (20') est un détecteur de phase selon l'une quelconque des revendications 1 à 3.

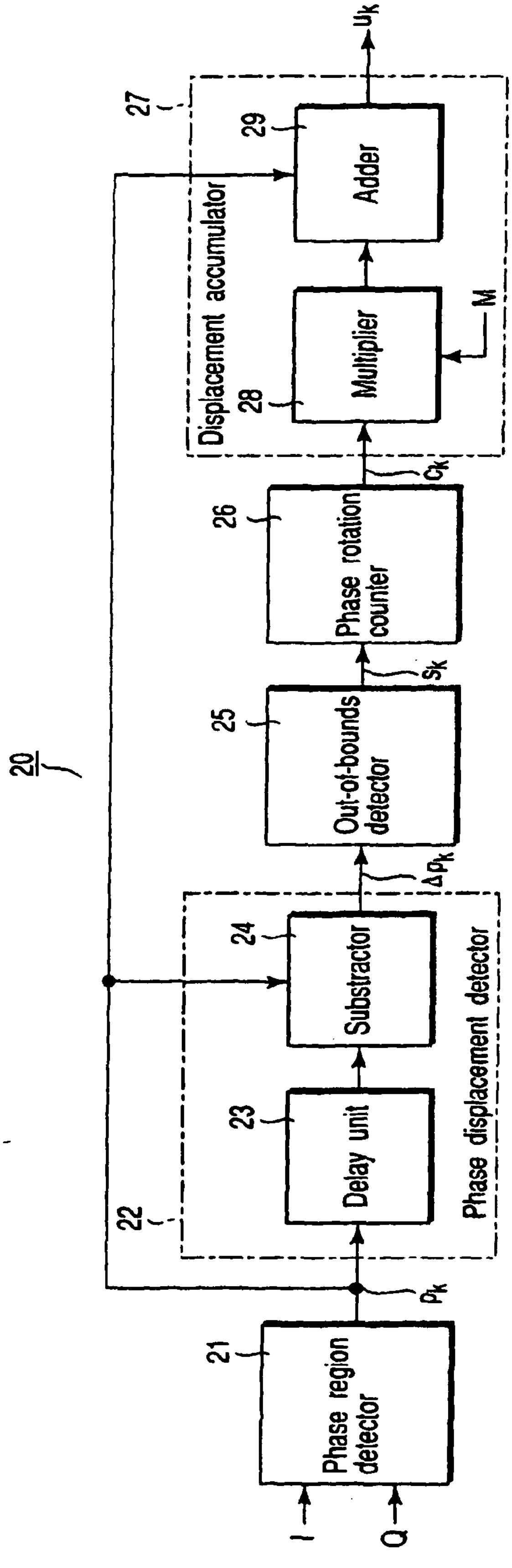

20
I
Q
21
Phase region detector
p_k
22
Phase displacement detector
23
Delay unit
24
Substractor
Δp_k
25
Out-of-bounds detector
s_k
26
Phase rotation counter
c_k
27
Displacement accumulator
28
Multiplier
M
29
Adder
u_k

FIG. 1

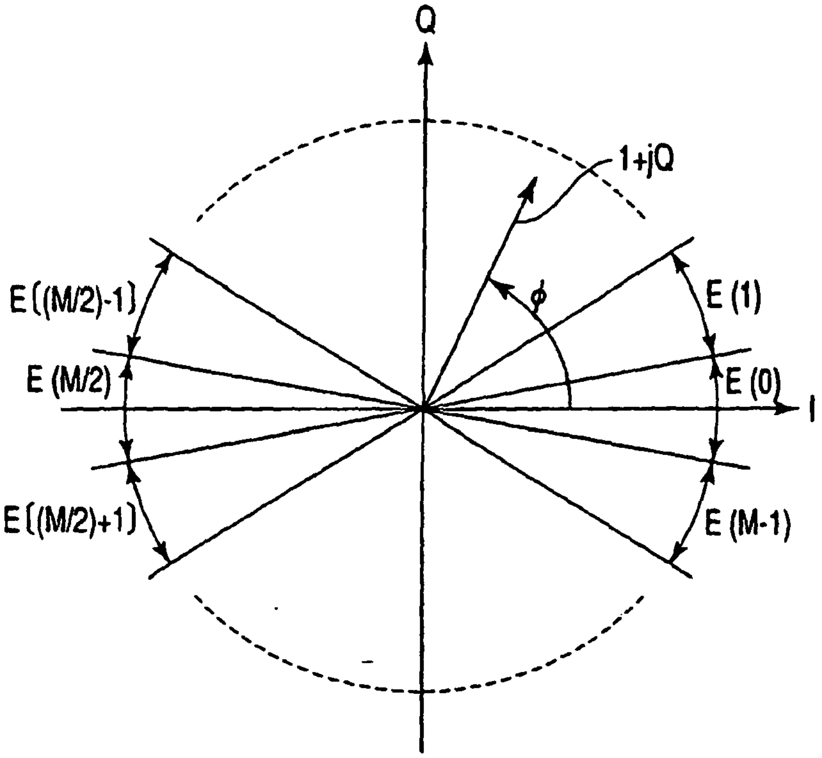


FIG. 2

		Range of Δp_k		
Number of regions M	Even	$-(M-1)\sim-([M/2]+1)$	$-[M/2]\sim[M/2]-1$	$[M/2]\sim M-1$
	Even	$-(M-1)\sim-[M/2]$	$-([M/2]-1)\sim[M/2]$	$[M/2]+1\sim M-1$
	Odd	$-(M-1)\sim-([M/2]+1)$	$-[M/2]\sim[M/2]$	$[M/2]+1\sim M-1$
Output s_k		$s_k=1$	$s_k=0$	$s_k=-1$

FIG. 3

FIG. 4A

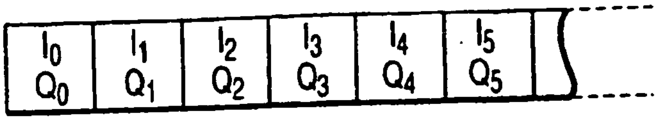


FIG. 4B

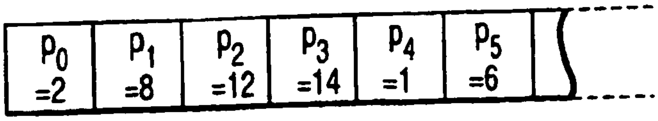


FIG. 4C

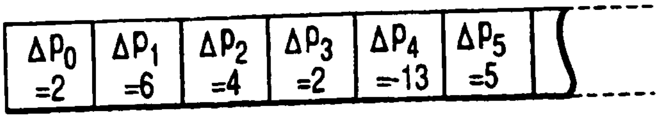


FIG. 4D

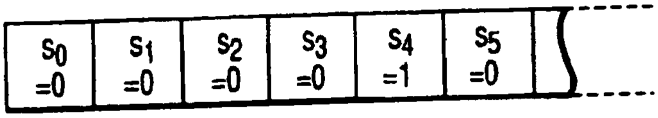


FIG. 4E

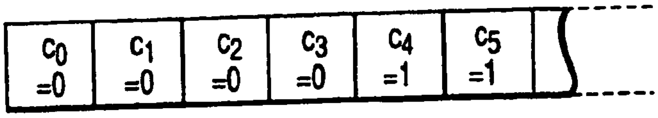
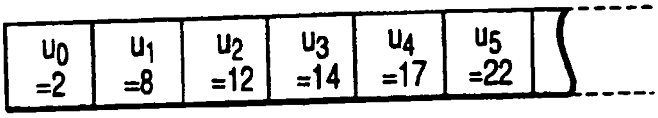


FIG. 4F



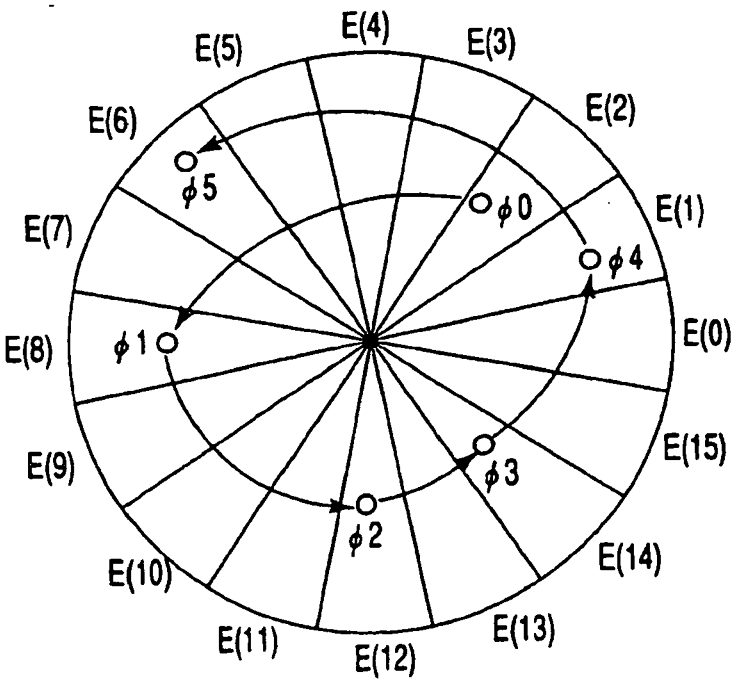


FIG. 5

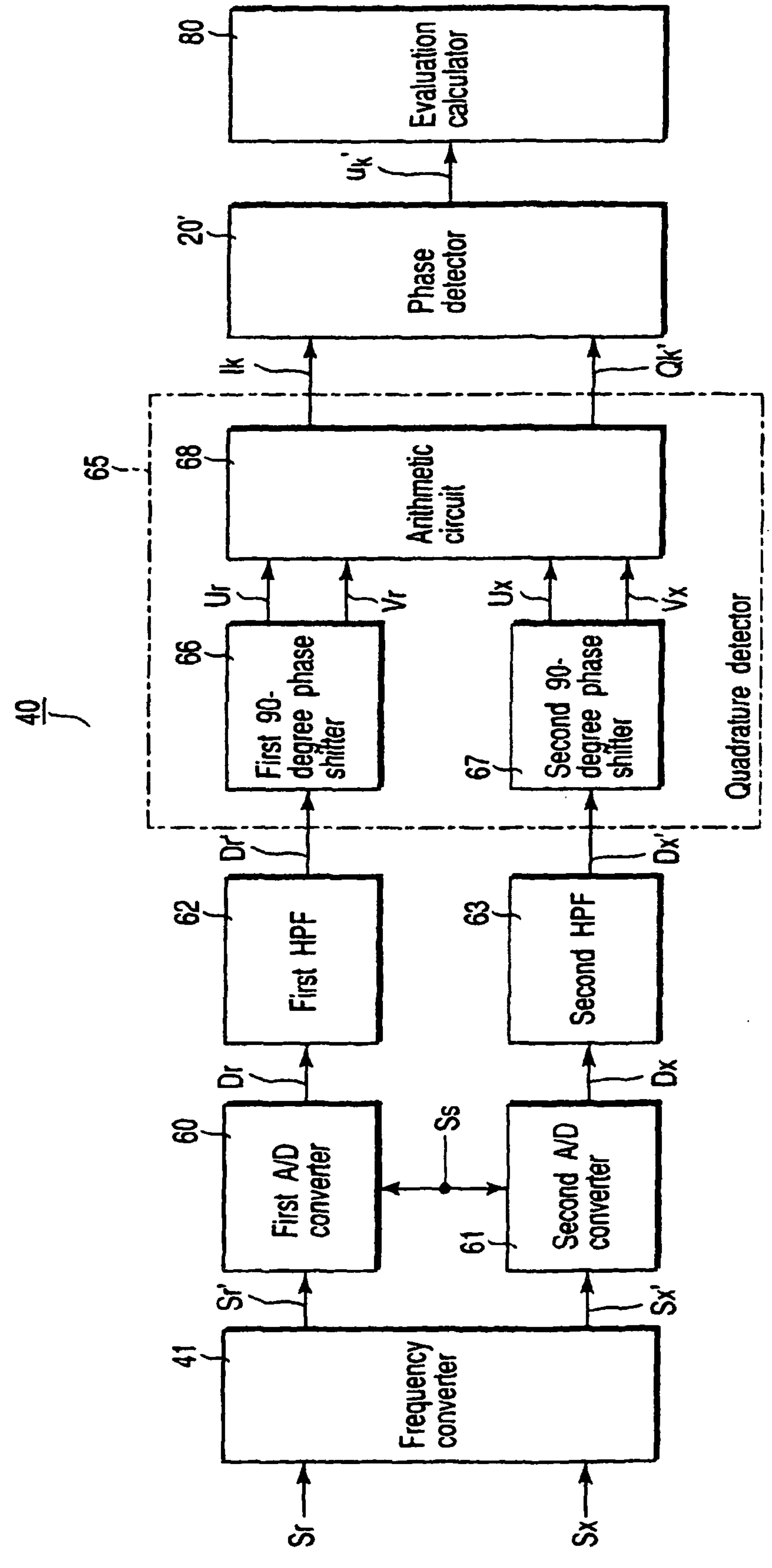

40
Sr
Sx
41
Frequency converter
Sr'
Sx'
60
First A/D converter
61
Second A/D converter
Ss
Dr
Dx
62
First HPF
63
Second HPF
Dr'
Dx'
65
66
First 90-degree phase shifter
67
Second 90-degree phase shifter
Ur
Vr
Ux
Vx
68
Arithmetic circuit
Quadrature detector
Ik
Qk'
20'
Phase detector
uk'
80
Evaluation calculator

FIG.6

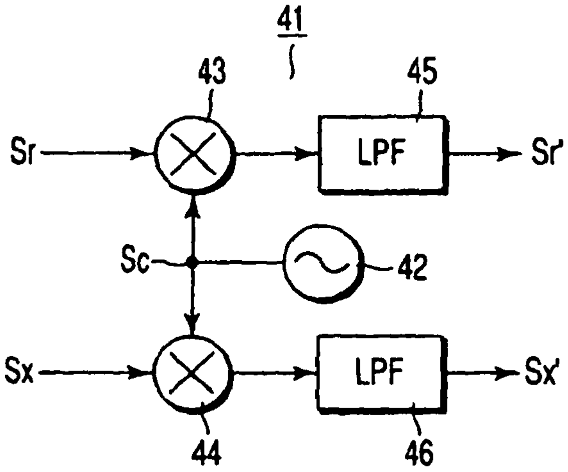


FIG.7

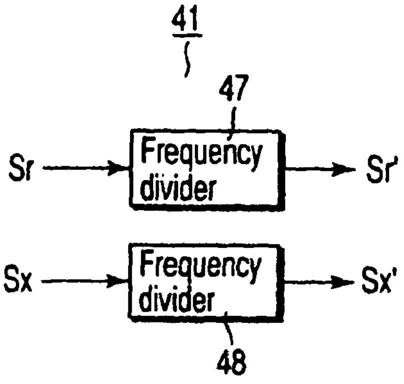


FIG.8

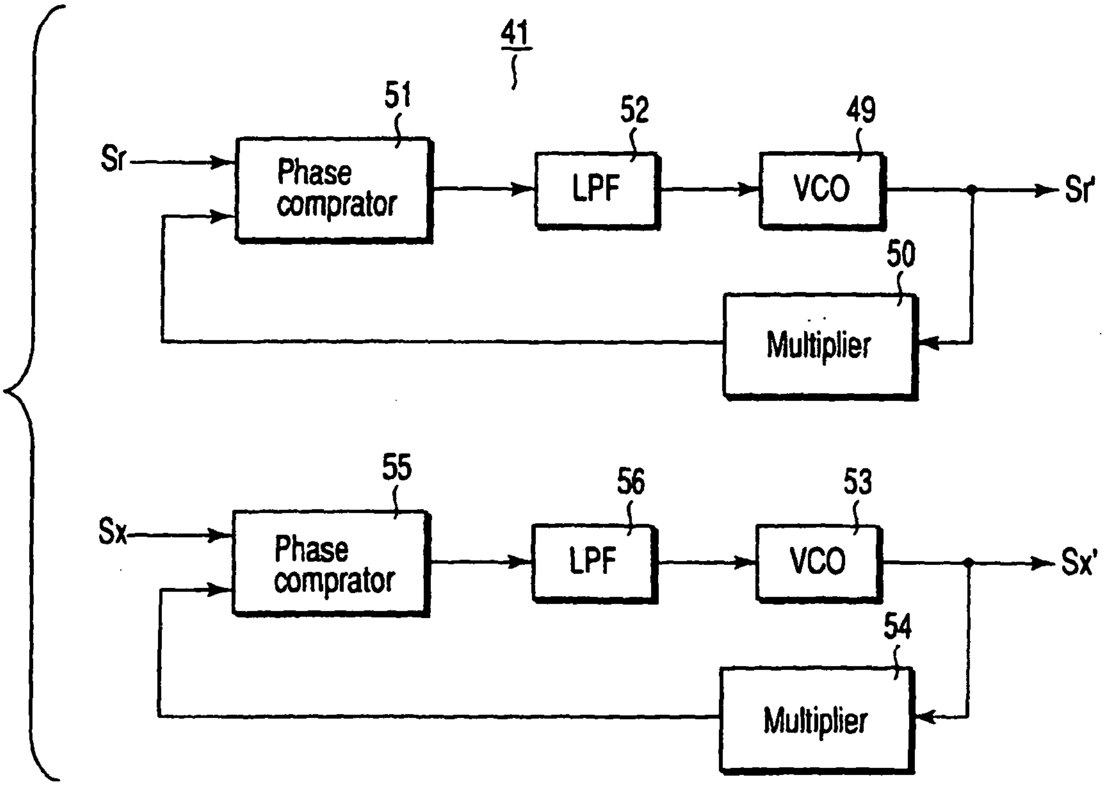


FIG.9

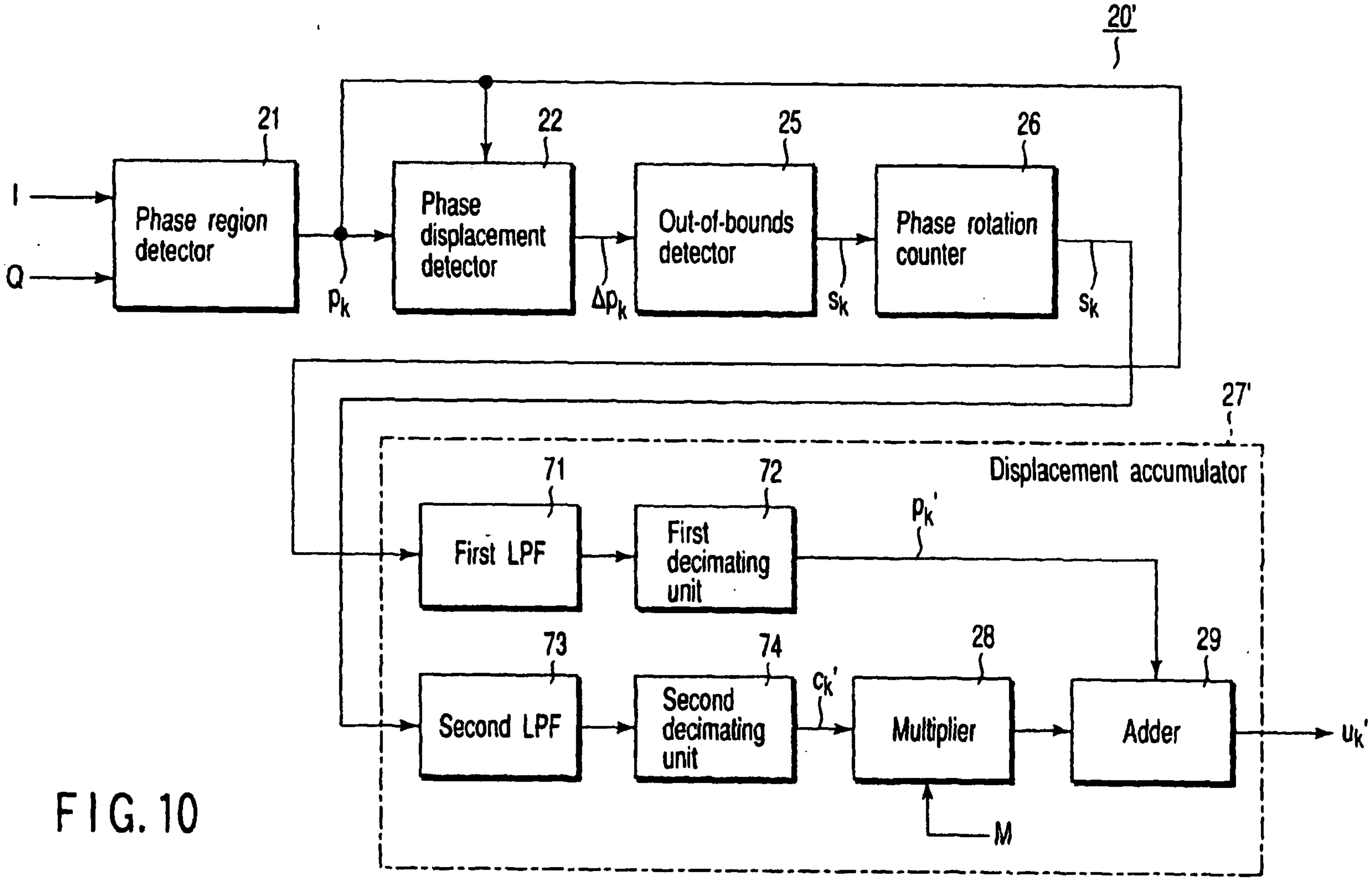
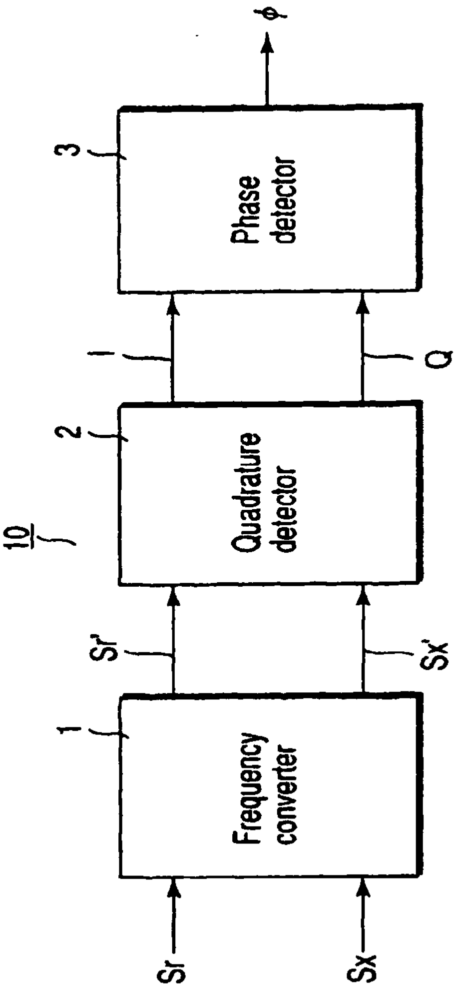
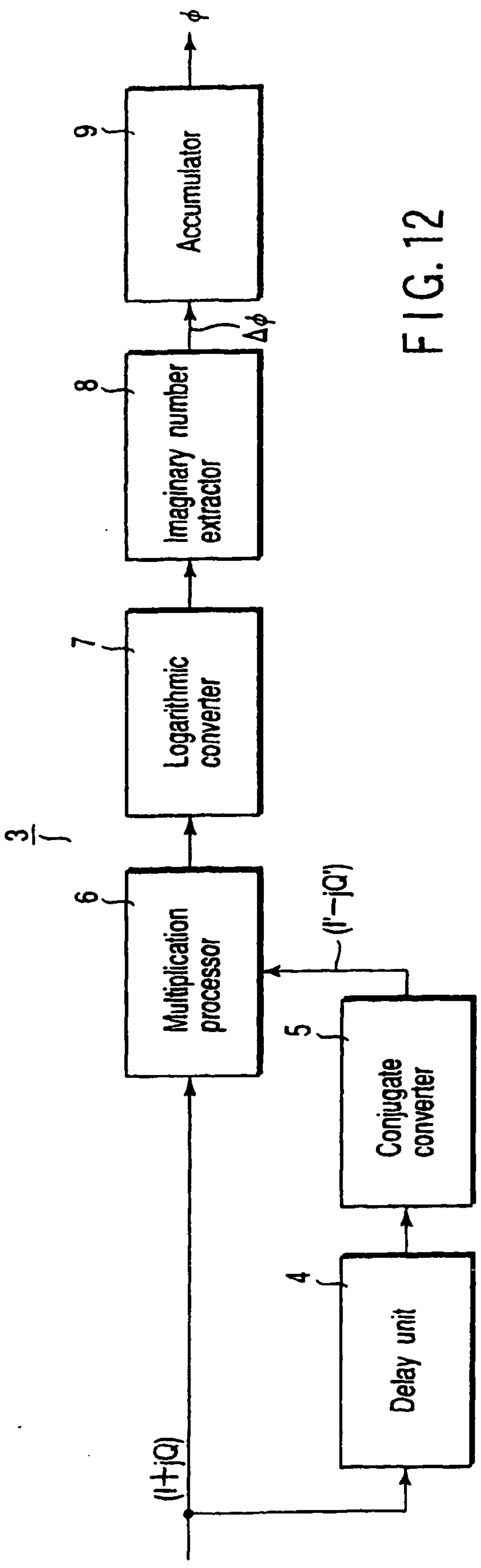

20'
I
Q
21
Phase region detector
p_k
22
Phase displacement detector
Δp_k
25
Out-of-bounds detector
s_k
26
Phase rotation counter
s_k
27'
Displacement accumulator
71
First LPF
72
First decimating unit
p_k'
73
Second LPF
74
Second decimating unit
c_k'
28
Multiplier
M
29
Adder
u_k'

FIG. 10


10
Sr
Sx
1
Frequency converter
Sr'
Sx'
2
Quadrature detector
I
Q
3
Phase detector
φ

F I G. 11


3
(I+jQ)
4
Delay unit
5
Conjugate converter
(I'−jQ')
6
Multiplication processor
7
Logarithmic converter
8
Imaginary number extractor
Δφ
9
Accumulator
φ

F I G. 12

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2001264370 A **[0016]**
- US 6310925 B **[0016]**

Non-patent literature cited in the description

- **MASAYA KIHARA ; SADAYASU ONO.** Elementary Digital Clock Technology. Ohm-Sha, 2001, 179-184 **[0006]**