

"SLIP PHASE CONTROL PHASE-LOCKED LOOP"

The present invention relates to a slip phase control phase-locked loop for generating a frequency-controlled output signal.

Analog and digital phase-locked loops (PLL) are widely used as highly-accurate frequency-controlled oscillators in radio communication systems or the like.

One example of PLL capable of producing an output signal having a high C/N (carrier signal/noise) ratio is a slip phase control PLL disclosed in Japanese Laid-Open Patent Publication No. 63(1988)-26589.

The disclosed slip phase control PLL has a voltage-controlled oscillator (VCO), a phase comparator, a low-pass filter (LPF), and a programmable frequency divider which comprises a pulse-swallow-type 2-scale-factor prescaler, a swallow counter, and a main counter.

The slip phase control PLL also includes a sawtooth generator for dividing a variable division ratio by $(n + q)$ (q is an integer other than 0) in each period T and generating a sawtooth wave having a period T . The output signal of the sawtooth generator is added or subtracted by the low-pass filter so that a slip phase waveform of the output signal from the phase comparator will be canceled out.

With the above arrangement, since no ripples are produced in a control voltage, particularly a low voltage,

applied to the varicap or the like of the VCO, the noise figure (NF) of the VCO is increased, and the VCO can produce an output signal of a high C/N ratio.

In the programmable frequency divider, when the 2-scale-factor prescaler has division ratios of 2^M and $2^M + 1$, the swallow counter counts m pulses according to a preset number m , and the main counter divides the input frequency by n according to a preset number n . During an m -counting period in which n pulses are being counted by the main counter, the 2-scale-factor prescaler divides the input frequency by $2^M + 1$, and during the remaining $(n - m)$ -counting period, the 2-scale-factor prescaler divides the input frequency by 2^M .

The total division ratio q of the programmable frequency divider is given by:

$$\begin{aligned} q &= m \times (2^M + 1) + (n - m) \times 2^M \\ &= m + 2^M \times n \end{aligned} \quad \dots(1)$$

The slip phase control PLL can control an oscillation frequency highly accurately, but is relatively complex in arrangement.

The preset number m varies from 0 to $2^M - 1$ in order to generate a signal to be supplied to the LPF for canceling out the slip phase waveform. Based on this fact, efforts to reduce the circuit scale are directed to the addition of a D/A converter which counts output pulses of the 2-scale-factor prescaler during an interval in which the

division ratio of the 2-scale-factor prescaler is of a constant value of 2^M .

However, the D/A converter has a D/A conversion range which is limited to a pulse count that ranges from 0 to $n - 2^M$, and hence cannot achieve a multiple-frequency output capability. The above drawbacks should be eliminated in view of demands for highly accurate frequency control, reduced circuit scales, and a reduced number of signal processing cycles.

The present invention provides a slip phase control phase-locked loop comprising: a voltage-controlled oscillator for generating a frequency signal; binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter; phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared signal, and applying the integrated signal to said voltage-controlled oscillator; and D/A converting means comprising a D/A converter swallow counter and a D/A converter main counter, said D/A converting means connected with said binary programmable frequency dividing means for D/A converting a

signal derived from said frequency signal and outputting a pulse-width-modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal at a preset count, wherein said pulse-width converted signal is integrated together with said phase-compared signal and applied to said voltage controlled oscillator.

The present invention also provides a slip phase control phase-locked loop comprising: a voltage-controlled oscillator for generating a frequency signal; binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter; phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared signal, and applying the integrated signal to said voltage-controlled oscillator; and a D/A converter counter connected with said main counter, said D/A converter causing said swallow counter to start counting, said D/A converter counter outputting a pulse-width modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal after said main counter has finished counting pulses, and for adding said pulse-width-modulated signal to said phase-compared signal.

The present invention further provides a slip phase control phase-locked loop comprising: a voltage-controlled oscillator for generating a frequency signal; binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter; phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared signal, and applying the integrated signal to said voltage-controlled oscillator; and a D/A converter counter connected with said swallow counter and said main counter, said swallow counter causing said D/A converter to start counting, said D/A converter counter outputting a pulse-width-modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal after said swallow counter has finished counting pulses, and for adding said pulse-width-modulated signal to said phase-compared signal.

Embodiments of the present invention will now be described by way of example only, with reference to the accompanying drawings, in which:-

FIG. 1 is a block diagram of a slip phase control PLL according to an embodiment of the present invention;

FIG. 2 is a block diagram of a slip phase control PLL according to another embodiment of the present invention; and

FIG. 3 is a block diagram of another programmable frequency divider unit for use in the slip phase control PLL shown in FIG. 2.

FIG. 1 shows a slip phase control PLL according to an embodiment of the present invention. The slip phase control PLL shown in FIG. 1 has a reference oscillator/divider 12, a quartz oscillator 12x, a phase comparator 14, a low-pass filter 16, a voltage-controlled oscillator (VCO) 18, and a programmable frequency divider 22.

When the VCO 18 is pulled in and locked in, it produces an output signal F_0 .

More specifically, a reference frequency signal F_R is produced by the reference oscillator/divider 12 and supplied to the phase comparator 14.

A signal F_C which is to be frequency-divided is supplied from the VCO 18 to the programmable frequency

divider 22, which applies a frequency-divided signal F_D having the same frequency as that of the reference frequency signal F_R to the phase comparator 14.

The phase comparator 14 supplies a phase-compared signal S_P to the low-pass filter 16, which applies an integrated control signal S_C to the VCO 18. The programmable frequency divider 22 supplies the low-pass filter 16 with a pulse-width converted signal D_{AP} which corresponds to a phase slip and a phase shift of the phase-compared signal S_P . At this time, the pulse-width converted signal D_{AP} and the phase-compared signal S_P are supplied to the low-pass filter 16 such that they cancel out each other. The control signal S_C produced by the low-pass filter 16 is in the form of a DC voltage (current) which therefore has reduced ripples.

The above basic mode of operation is known from Japanese Laid-Open Patent Publication No. 63(1988)-26589, for example, and will not be described in further detail.

The programmable frequency divider 22, which is an essential feature of the present invention, will now be described below.

The programmable frequency divider 22 has a 2-scale-factor prescaler 32 which is supplied with the signal F_C to be frequency-divided and which has selectable division ratios, a swallow counter 34, a main counter 36, a D/A converter swallow counter 38, a D/A converter main counter 40, and a gate 42.

The frequency-divided signal F_D and the pulse-width converted signal D_{AP} are generated by the programmable frequency divider 22 as follows:

Denoted at C_K is an intermediate frequency-divided clock signal, ST_1 a starting signal for the programmable frequency divider 22, ST_2 and ST_0 starting and disabling signals, respectively, for the swallow counter 34, MOD a division control signal for the 2-scale-factor prescaler 32, MOD_1 an output signal from the swallow counter 34, MOD_2 an output signal from the D/A converter swallow counter 38, m and n division ratio setting codes (numbers), and p and q D/A conversion setting codes (numbers).

The swallow counter 34 counts $(m + 2^M)$ pulses of the intermediate frequency-divided clock signal C_K according to the division ratio setting code m . The main counter 36 counts $(n - 1)$ pulses of the clock signal C_K according to the division ratio setting code n . The D/A converter swallow counter 38 counts p pulses of the clock pulse C_K according to the D/A conversion setting code p . The D/A converter main counter 40 counts $(q + 2^M)$ pulses and also counts the clock signal C_K according to the D/A conversion setting code q .

The 2-scale-factor prescaler 32 divides the frequency of the signal F_C by $2^M + 1$ during an interval in which the division control signal MOD is of a high (H) level, and divides the frequency of the signal F_C by

2^M during an interval in which the division control signal M_{OD} is of a low (L) level. The intermediate frequency-divided clock signal C_K is produced by the prescaler 32 when the signal F_C is frequency-divided in this manner.

The main counter 36 frequency-divides the intermediate frequency-divided clock signal C_K by $n - 1$, thus producing the frequency-divided signal F_D , and delivers the starting signal S_{T1} each time it counts $(n - 1)$ pulses.

In response to the starting signal S_{T1} , the D/A converter main counter 40 renders the pulse-width converted signal D_{AP} high in level during an interval in which it counts $(q + 2^M)$ pulses of the intermediate frequency-divided clock signal C_K . After having counted the $(q + 2^M)$ pulses, the D/A converter main counter 40 delivers the starting signal S_{T2} . The D/A converter main counter 40 keeps the pulse-width converted signal D_{AP} low in level until the next starting signal S_{T1} is applied thereto.

The D/A converter swallow counter 38 is responsive to the starting signal S_{T1} for rendering the output signal M_{OD2} high in level during an interval in which it counts p pulses of the intermediate frequency-divided clock signal C_K . After having counted the p pulses, the D/A converter swallow counter 38 generates the disabling signal S_{T0} . The D/A converter swallow counter 38 maintains the output signal M_{OD2} at a low level until it is supplied with the next starting signal S_{T1} .

When the starting signal ST_1 is supplied, the swallow counter 34 counts p pulses of the intermediate frequency-divided clock signal C_K while the D/A converter swallow counter 38 is counting the p pulses. After the swallow counter 34 has been disabled by the disabling signal ST_0 , it counts again the clock signal C_K when supplied with the starting signal ST_2 . While the swallow counter 34 is counting the remaining $(m + 2^M - p)$ pulses of the clock signal C_K , it keeps the output signal MOD_1 high in level. The swallow counter 34 keeps the output signal MOD_1 low in level until it is supplied with the next starting signal ST_2 .

The gate 42 renders the division control signal MOD high in level when either one of the supplied output signals MOD_1 , MOD_2 is high in level. The gate 42 keeps the division control signal MOD low in level only when both output signals MOD_1 , MOD_2 are low in level.

The total division ratio d of the programmable frequency divider 22 is expressed by:

$$\begin{aligned} d &= (2^M + 1) \times (m + 2^M) + 2^M \times \{n - 1 - (m + 2^M)\} \\ &= m + 2^M \times n \end{aligned} \quad \dots (2)$$

The number e of counted pulses of the pulse-width converted signal D_{Ap} is given by:

$$\begin{aligned} e &= (2^M + 1) \times p + 2^M \times (q + 2^M - p) \\ &= p + 2^M \times q + 2^{2M} \end{aligned} \quad \dots (3)$$

The train of pulses from the D/A converter main counter 40 has a pulse width ratio w as follows:

$$w = \frac{p + 2^M \times q + 2^{2M}}{m + 2^M \times n} \quad \dots(4)$$

When the pulse train is averaged, there is obtained a D/A-converted voltage (or current) which is proportional to $p + 2^M \times q + 2^{2M}$, i.e., the pulse-width converted signal D_{AP} .

The codes m , n , p , q are subject to the following limitations:

$$0 \leq p < 2^M, 0 \leq m < 2^M, q + 2^{M+1} < n \quad \dots(5)$$

For example, when $M = 5$ (i.e., the division ratios of the 2-scale-factor prescaler 32 are 32, 33), if the D/A conversion setting code q is of 5 bits, then since the D/A conversion setting code p is also of 5 bits,

$$0 \leq p + 2^5 \times q < 2^{10} \quad \dots(6)$$

Therefore, it is possible to effect a D/A conversion process with the accuracy of 1024 points, i.e., 10 bits.

Inasmuch as there can be obtained a highly accurate D/A converted voltage (or current) corresponding to a phase slip and a phase shift during a time period T in which the signal F_C is being frequency-divided by $(n \cdot 2^M + m)$, the VCO 18 can produce a highly accurate output signal F_O which has a high C/N ratio and a good NF.

The slip phase control PLL of the aforesaid construction is of a relatively simple arrangement for a reduced circuit scale and signal processing scale, and can control an oscillation frequency with high accuracy.

FIG. 2 shows a slip phase control PLL according to another embodiment of the present invention. The slip phase

control PLL shown in FIG. 2 has a reference oscillator/divider 112, a quartz oscillator 112x, a phase comparator 114, a low-pass filter 116, a voltage-controlled oscillator (VCO) 118, and a programmable frequency divider 122A.

When the VCO 118 is pulled in and locked in, it produces an output signal F_0 . The operation of the reference oscillator/divider 112, the quartz oscillator 112x, the phase comparator 114, the low-pass filter 116, and the VCO 118 is the same as that of those shown in FIG. 1, and will not be described in detail.

The programmable frequency divider 122A, which is an essential feature of the present invention, will now be described below.

The programmable frequency divider 122A has a 2-scale-factor prescaler 132 which is supplied with the signal F_C to be frequency-divided and which has selectable division ratios, a swallow counter 134, a main counter 136, and a D/A converter counter 140.

The frequency-divided signal F_D and the pulse-width converted signal D_{AP} are generated by the programmable frequency divider 122A as follows:

Denoted at C_K is an intermediate frequency-divided clock signal, S_{T1} a starting signal for the programmable frequency divider 122A, S_{T2} a starting signal for the swallow counter 134, M_{OD} a division control signal for the 2-scale-factor prescaler 132, m and n division ratio setting

codes (numbers), and p a D/A conversion setting code (number).

The 2-scale-factor prescaler 132 divides the frequency of the signal F_C by $2^M + 1$ during an interval in which the division control signal M_{OD} is of a high (H) level, and divides the frequency of the signal F_C by 2^M during an interval in which the division control signal M_{OD} is of a low (L) level. The intermediate frequency-divided clock signal C_K is produced by the prescaler 32 when the signal F_C is frequency-divided in this manner.

When the starting signal ST_2 is supplied, the swallow counter 134 keeps the division control signal M_{OD} high in level while it is counting m pulses of the intermediate frequency-divided clock signal C_K . The swallow counter 134 then keeps the division control signal M_{OD} low in level until the next starting signal ST_2 is supplied.

The main counter 136 frequency-divides the intermediate frequency-divided clock signal C_K by n , thus producing the frequency-divided signal F_D , and delivers the starting signal ST_1 each time it counts n pulses.

In response to the starting signal ST_1 , the D/A converter counter 140 renders the pulse-width converted signal D_{Ap} high in level during an interval in which it counts p pulses of the intermediate frequency-divided clock signal C_K . After having counted the p pulses, the D/A converter counter 140 delivers the starting signal ST_2 . The D/A

converter counter 140 keeps the pulse-width converted signal D_{AP} low in level until the next starting signal S_{T1} is applied thereto.

FIG. 3 shows another programmable frequency divider 122B which can be used in place of the programmable frequency divider 122A in the slip phase control PLL illustrated in FIG. 2.

The programmable frequency divider 122B is essentially the same as the programmable frequency divider 122A except that the starting signal S_{T1} is supplied to the swallow counter 134 and another starting signal S_{T21} is supplied to a D/A converter counter 141.

Denoted at C_K is an intermediate frequency-divided clock signal, S_{T1} a starting signal for the programmable frequency divider 122B, S_{T21} a starting signal for the D/A converter counter 141, M_{OD} a division control signal for the 2-scale-factor prescaler 132, m and n division ratio setting codes (numbers), and p a D/A conversion setting code (number).

The 2-scale-factor prescaler 132 divides the frequency of the signal F_C by $2^M + 1$ during an interval in which the division control signal M_{OD} is of a high (H) level, and divides the frequency of the signal F_C by 2_M during an interval in which the division control signal M_{OD} is of a low (L) level. The intermediate frequency-divided clock signal C_K is produced by the prescaler 32 when the signal F_C is frequency-divided in this manner.

When the starting signal S_{T1} is supplied, the swallow counter 134 keeps the division control signal M_{OD} high in level while it is counting m pulses of the intermediate frequency-divided clock signal C_K . The swallow counter 134 generates the starting signal S_{T21} when it completes the counting of the m pulses of the clock signal C_K . The swallow counter 134 then keeps the division control signal M_{OD} low in level until the next starting signal S_{T1} is supplied.

The main counter 136 frequency-divides the intermediate frequency-divided clock signal C_K by n , thus producing the frequency-divided signal F_D , and delivers the starting signal S_{T1} each time it counts n pulses.

In response to the starting signal S_{T21} , the D/A converter counter 141 renders the pulse-width converted signal D_{Ap} high in level during an interval in which it counts p pulses of the intermediate frequency-divided clock signal C_K . The D/A converter counter 141 then keeps the pulse-width converted signal D_{Ap} low in level until the next starting signal S_{T21} is applied thereto.

The total division ratio q'' of the programmable frequency dividers 122A, 122B is expressed by:

$$\begin{aligned} q'' &= (2^{M_{OD}} + 1) \times m + 2^M \times (n - m) \\ &= m + 2^M \times n \end{aligned} \quad \dots (7)$$

The number e of counted pulses of the pulse-duration converted signal D_{Ap} is given by: $e = 2^M \times p$

The train of pulses from the D/A converter counter has a pulse duration ratio d as follows:

$$d = \frac{2^M}{m + 2^M \times n} \times p \quad \dots(8)$$

When the pulse train is averaged, there is obtained a D/A-converted voltage (or current) which is proportional to p , i.e., the pulse-width converted signal D_{Ap} .

Since the relationship $n \geq 2^{M+1} + p$ must be satisfied in order to obtain a continuously variable division ratio, the division ratio q which is continuously variable is given by:

$$q \geq 2^M \times (2^M + p) = 2^{M+1} + 2^M \times p \quad \dots(9)$$

In the range of $0 \leq p \leq q - 2^M$, there can be obtained a highly accurate averaged D/A converted voltage (or current), i.e., the pulse-width converted signal D_{Ap} , which is proportional to the D/A conversion setting code (number) p and inversely proportional to $m + 2^M \times n$, and hence the VCO 118 can produce a highly accurate output signal F_0 which has a high C/N ratio and a good NF.

As can be understood from the above description, the D/A converter counter produces a D/A-converted signal which is proportional to the pulse count and inversely proportional to the total division ratio, and the total division ratio is controlled by the swallow counter and the main counter. The limitation which the successive division ratios are subject to is 2^{M+1} or higher, and the input signal can be frequency-divided by n according to the preset number n for the main counter without any special addition or subtraction processes.

The slip phase control PLL according to the present invention is relatively simple in arrangement for highly accurately canceling out a slip phase waveform of the phase-compared output signal, which is applied to the VCO to control the oscillation frequency with a high C/N ratio.

The preferred embodiments of the present invention can provide a slip phase control PLL which can generate a high-frequency local oscillation signal or transmitted oscillation signal at successive intervals or steps in a radio transmitter/receiver or the like.

The preferred embodiments of the present invention can also provide a slip phase control PLL which has a relatively simple circuit arrangement to reduce a circuit scale and a signal processing scale and which controls an oscillated frequency highly accurately.

Although certain preferred embodiments have been shown and described, it should be understood that many changes and modifications may be made therein without departing from the scope of the appended claims.

CLAIMS:

1. A slip phase control phase-locked loop comprising:
a voltage-controlled oscillator for generating a frequency signal;

binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter;

phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared signal, and applying the integrated signal to said voltage-controlled oscillator; and

D/A converting means comprising a D/A converter swallow counter and a D/A converter main counter, said D/A converting means connected with said binary programmable frequency dividing means for D/A converting a signal derived from said frequency signal and outputting a pulse-width-modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal at a preset count, wherein said pulse-width converted signal is integrated together with said phase compared signal and applied to said voltage controlled oscillator.

2. A slip phase control phase-locked loop comprising:
a voltage-controlled oscillator for generating a frequency signal;

binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter;

phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared



signal, and applying the integrated signal to said voltage-controlled oscillator; and

a D/A converter counter connected with said main counter, said D/A converter causing said swallow counter to start counting, said D/A converter counter outputting a pulse-width modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal after said main counter has finished counting pulses, and for adding said pulse-width-modulated signal to said phase-compared signal.

3. A slip phase control phase-locked loop comprising:

a voltage-controlled oscillator for generating a frequency signal;

binary programmable frequency dividing means for producing a frequency-divided signal in response to said frequency signal supplied thereto, said binary programmable frequency dividing means including a 2-scale-factor prescaler, a swallow counter and a main counter;

phase-comparing/integrating means for comparing the phase of said frequency-divided signal with the phase of a reference frequency signal, integrating a phase-compared signal, and applying the integrated signal to said voltage-controlled oscillator; and

a D/A converter counter connected with said swallow counter and said main counter, said swallow counter causing said D/A converter to start counting, said D/A converter counter outputting a pulse-width-modulated signal corresponding to a phase slip and a phase shift of said phase-compared signal after said swallow counter has finished counting pulses, and for adding said pulse-width-modulated signal to said phase-compared signal.

4. A slip phase control phase-locked loop substantially as hereinbefore described with reference to Figure 1 or Figures 2 to 3.



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