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2 "Ripple-Free Phase Detector Using Two Sample-and-Hold Circuits"

3

4 The present invention relates generally to phase detectors for phase
5 lock loops, and more specifically to a sample-and-hold phase detector which
6 generates a ramp voltage proportional to a phase difference between two
7 input signals and samples and holds the ramp voltage to produce a phase
8 detector output.

9 According to the prior art sample-and-hold phase detector, a "ramp"
10 capacitor is charged for an interval corresponding to a phase difference
11 between an input signal and a reference signal to develop a ramp voltage
12 proportional to the phase difference. A sample-and-hold circuit is
13 connected to the ramp capacitor to sample and hold the ramp voltage in
14 response to a sampling pulse. With the recent tendency toward LSI
15 implementation of electronic circuitry, it is desirable to fabricate all
16 components of the sample-and-hold circuit on a single LSI chip. However,
17 the value of the storage capacitor of the sample-and-hold circuit cannot be
18 made sufficiently large to prevent the applied sampling pulse from
19 bypassing the "sample" switch of the sample-and-hold circuit by way of its
20 parasitic capacitance to its "hold" capacitor. Therefore, the phase detector
21 output contains an undesirable ripple voltage which occurs at the same
22 frequency as the reference signal.

23

24 It is therefore an object of the present invention to provide a phase
25 detector which enables the implementation of sample-and-hold phase
26 detectors using LSI technology.

27 According to the present invention, a ramp voltage generator is
28 provided for receiving a reference pulse of a constant frequency and an
29 input pulse from an external source and producing a ramp voltage
30 proportional to the phase difference between these pulses. A first sample-

1 and-hold circuit samples the ramp voltage in response to a sampling pulse
2 and holds the sampled voltage. Further provided is a second sample-and-
3 hold circuit which is also responsive to the sampling pulse for sampling a
4 constant voltage and holding the sampled voltage. The voltages sampled
5 by the first and second sample-and-hold circuits are input to a subtractor
6 where the voltage difference between the input voltages is detected.
7 Undesirable ripple components, which are generated by the two sample-
8 and-hold circuits, are effectively cancelled out by the subtractor.

9 Preferably, a delay circuit is provided to receive the reference pulse as
10 a first reference pulse and delay it to produce a second reference pulse. A
11 second ramp voltage generator produces the constant voltage that is
12 proportional to the interval between the first and second reference pulses.
13

14 The present invention will be described in further detail with reference
15 to the accompanying drawings, in which:

16 Fig. 1 is a block diagram of a phase detector according to the present
17 invention;

18 Fig. 2 shows details of each of the switches used in Fig. 1; and

19 Fig. 3 is a timing diagram showing waveforms of the various signals
20 generated in Fig. 1.

21

22 Referring now to Fig. 1, the phase detector of the present invention
23 comprises a first sample-and-hold circuit 30 and a second sample-and-
24 hold circuit 31. First sample-and-hold circuit 30 includes a storage
25 capacitor 5 connected between ground and the input of a buffer amplifier
26 3, and a sampling switch 10 connected between a first ramp capacitor 7
27 and the input of amplifier 3. A first charge timing switch 11 is connected to
28 the ramp capacitor 7 for charging it with a current supplied from a p-
29 channel MOS (metal oxide semiconductor) transistor 15 in response to a
30 charge command pulse CP1 from a control circuit 32. A first discharge

1 timing switch 13 is connected to the ramp capacitor 7 for discharging it in
2 response to a discharge command pulse DP. Therefore, a first ramp
3 voltage is developed across the first ramp capacitor 7. The sampling
4 switch 9 is responsive to a sampling pulse SP from the control circuit to
5 sample and transfer the energy stored in the first ramp capacitor 7 into the
6 storage capacitor 5 where the sampled voltage is held until the next
7 sampling instant.

8 Likewise, the second sample-and-hold circuit 31 includes a storage
9 capacitor 6 connected to the input of a buffer amplifier 4, and a sampling
10 switch 12 connected between a second ramp capacitor 7 and the input of
11 amplifier 4. A second charge timing switch 12 is connected to the second
12 ramp capacitor 8 for charging it with a current supplied from a p-channel
13 MOS transistor 16 in response to a pulse CP2 from the control circuit. A
14 second discharge timing switch 14 is connected to the second ramp
15 capacitor 8 for discharging it in response to the discharge command pulse
16 DP. Therefore, a second ramp voltage is developed across the capacitor
17 7. The sampling switch 9 is responsive to the sampling pulse SP to sample
18 and transfer the energy stored in the second ramp capacitor 7 into the
19 storage capacitor 5 to hold the sampled voltage.

20 Transistors 15 and 16 are of identical structure and their gate
21 electrodes are connected together to the gate electrode of a p-channel
22 MOS transistor 17 which is connected to ground through a resistor 18.
23 Specifically, transistor 17 provides a drain current I_a which is given by:

$$24 \quad I_a = (V_{DD} - V_{GS})/R \quad (1)$$

25 where V_{DD} is the source voltage and V_{GS} is the gate-source voltage of
26 transistor 17, and R is the value of resistor 18. Transistor 15 forms a current
27 mirror circuit with transistor 17 and the drain current I_b of transistor 15 is:

$$28 \quad I_a = (I_b)(N_1) \quad (2)$$

29 where $N_1 = (W_{16}/L_{16})(L_{17}/W_{17})$, where W_{16} and W_{17} are channel widths
30 of transistors 15, 17, and L_{15} and L_{17} are channel lengths of transistors 15,

17. Likewise, transistor 16 forms a current mirror circuit with transistor 17, and therefore, the drain current I_C of transistor 16 is given by:

$$I_a = (I_C)(N_2) \quad (3)$$

where $N_2 = (W_{16}/L_{16})(L_{17}/W_{17})$, where W_{16} and L_{16} are the channel width and length of transistor 15, respectively. Since transistors 15 and 16 of identical structure, $N_1 = N_2 = N$, and hence, currents I_D and I_C are of the same value and are uniquely determined by resistor 18. Therefore, the voltages developed in the first and second ramp capacitors 7 and 8 are respectively linearly proportional to the duration of the charge command pulses CP1 and CP2.

All capacitors of the phase detector are implemented using LSI technology and incorporated into the same LSI chip with other circuit elements of the phase detector.

As shown in Fig. 2, all switches of the phase detector are implemented with analog transmission gates that allows a voltage of any amplitude value to be passed from its input to its output in response to a switching pulse applied from the control circuit. Each switch comprises a pair of complementary MOS transistors 37 and 38 with the source and drain electrodes of each transistor being connected to the corresponding electrodes of the other and the gate of transistor 38 being coupled through an inverter 39 to the gate of transistor 37.

The outputs of buffer amplifiers 3 and 4 are coupled respectively to inputs of a differential amplifier, or subtractor 2, which is typically implemented with an operational amplifier 20, resistors 20, 21 through which the buffer amplifier outputs are respectively coupled to the inverting and noninverting inputs of the operational amplifier, and a resistor 23 coupling the noninverting input to ground. The output of operational amplifier 20 is connected to the phase detector output terminal 1.

Control circuit 32, driven by externally generated clock pulses, receives a reference pulse which occurs at interval T and an input pulse supplied

1 from an external source. The phase timing of the input pulse is compared
2 with the reference pulse to produce a first charge timing pulse CP1 of
3 duration corresponding to the phase difference θ as shown in Fig. 3. The
4 reference pulse is also input to a delay circuit 33 where it is delayed by a
5 prescribed interval ϕ to produce a delayed reference pulse, which is input
6 to control circuit 32. Control circuit 32 produces a second charge timing
7 pulse CP2 of duration corresponding to the prescribed interval ϕ . Control
8 circuit 32 further generates a sampling pulse SP and a discharge timing
9 pulse DP in succession during the interval between the trailing edge of a
10 reference pulse and the leading edge of the next reference pulse.

11 The following is a description of the operation of the phase detector of
12 the present invention with reference to Fig. 3.

13 When the phase detector receives a reference pulse 40 and an input
14 pulse 41 at intervals θ , a CP1 command pulse 43 of duration θ is output
15 from control circuit 32 to the first charge timing switch 11, thus drawing a
16 current I_b from the transistor 15 into the first ramp capacitor 7 to develop a
17 ramp voltage V_1 which is given by:

$$18 \quad V_1 = (I_b)(\theta)(T)/(2\pi)(C_7) \quad (4)$$

19 where C_7 is the value of ramp capacitor 7 and the delay interval θ is given
20 in units of radian. By substituting Equation (2) into Equation (4), the
21 following relation is obtained:

$$22 \quad V_1 = (\theta)(T)(N)(V_{DD} - V_{GS})/(2\pi)(C_7)(R) \\ 23 \quad = (K)(\theta)/(C_7)(R) \quad (5)$$

24 where K is the phase-to-voltage conversion coefficient and is given by the
25 relation $(T)(N)(V_{DD} - V_{GS})/2\pi$.

26 Concurrently, a CP2 command pulse 44 of duration ϕ is applied to the
27 second charge timing switch 12. A current I_c is drawn from the transistor
28 16 into the second ramp capacitor 8 ($=C_8$) to develop a ramp voltage V_2
29 which is given by:

$$30 \quad V_2 = (I_c)(\phi)(T)/(2\pi)(C_8) \quad (6)$$

$$\begin{aligned} &= (\phi)(T)(N)(V_{DD} - V_{GS})/(2\pi)(C_8)(R) \\ &= (K)(\phi)/(C_8)(R) \end{aligned} \quad (7)$$

In response to a sampling pulse 45 the first and second sampling switches 9 and 10 are operated to sample and transfer the voltages V_1 and V_2 from the ramp capacitors 7 and 8 to the storage capacitors 3 and 4, respectively. A discharge command pulse 46 is then input to switches 13 and 14 to discharge the ramp capacitors 7 and 8 completely. If the value of each storage capacitor is much smaller than the value of the corresponding ramp capacitor, the voltages stored in the capacitors 3 and 4 are substantially equal to voltages V_1 and V_2 , respectively.

Through buffer amplifiers 3 and 4, the sampled voltages V_1 and V_2 appear respectively as voltages V_A and V_B at the inputs of subtractor 2 where the difference between the input voltages V_A and V_B is detected and output to the terminal 1.

Because of the small capacitance values of the storage capacitors 3 and 4, a feedthrough effect occurs through the sampling switches 9 and 10. Therefore, the sampling pulse applied to the first sample-and-hold circuit 30 finds a leakage path through switch 9 to capacitor 5 to develop a ripple voltage, as indicated by hatching 47, which is superposed on the sampled voltage V_1 . In like manner, the sampling pulse applied to the second sample-and-hold circuit 31 finds a leakage path through switch 10 to capacitor 6 to develop a ripple of the same magnitude as ripple voltage 47, as indicated by hatching 48, which is superposed on the sampled voltage V_2 . However, due to the differential action of subtractor 2, the leakage voltages 47 and 48 are cancelled out, thus producing a phase detector output voltage V_O indicative of the difference between voltages V_A and V_B at the output terminal 1.

Since the second ramp voltage attains a constant level in so far as the interval between the non-delayed and delayed reference pulses remains constant, it could equally be as well provided by an external source of

- 1 constant voltage, instead of by the ramp voltage generating circuit formed
- 2 by capacitor 8, switches 12, 14, delay circuit 33 and control circuit 32.

CLAIMS:

- 1 1. A phase detector comprising:
2 ramp voltage generating means for receiving a reference pulse of a
3 predetermined constant frequency and an input pulse and developing a
4 ramp voltage proportional to a phase difference between the reference
5 pulse and said input pulse;
6 means for generating a sampling pulse subsequent to the reference
7 pulse;
8 first sample-and-hold means for sampling said ramp voltage in
9 response to the sampling pulse;
10 second sample-and-hold means for sampling a constant voltage in
11 response to said sampling pulse; and
12 means for detecting a voltage difference between the voltages
13 sampled by said first and second sample-and-hold means.

- 1 2. A phase detector as claimed in claim 1, further comprising:
2 delay means for receiving said reference pulse as a first reference pulse
3 and producing a second reference pulse delayed by a prescribed interval
4 with respect to the first reference pulse; and
5 second ramp voltage generating means for receiving said first and
6 second reference pulses and developing said constant voltage
7 proportional to said prescribed interval.

- 1 3. A phase detector comprising:
2 a first integrated-circuit capacitor;
3 charging means for receiving a reference pulse of a predetermined
4 constant frequency and an input pulse, and drawing a current at a constant
5 rate into the first integrated-circuit capacitor during an interval
6 corresponding to a phase difference between the reference pulse and said



7 input pulse to develop a ramp voltage in said first integrated-circuit
8 capacitor;
9 a first integrated-circuit sample-and-hold circuit connected to said first
10 integrated-circuit capacitor;
11 second integrated-circuit sample-and-hold circuit connected to a
12 source of constant voltage;
13 sampling means for causing said first and second integrated-circuit
14 sample-and-hold circuits to sample said ramp voltage and said constant
15 voltage, respectively, during an interval subsequent to said reference pulse;
16 and
17 means for detecting a voltage difference between the voltages
18 sampled by said first and second sample-and-hold circuits.

1 4. A phase detector as claimed in claim 3, wherein said source of
2 constant voltage comprises:
3 delay means for receiving said reference pulse as a first reference pulse
4 and producing a second reference pulse delayed by a prescribed interval
5 with respect to the first reference pulse;
6 a second integrated-circuit capacitor; and
7 second charging means for receiving said first and second reference
8 pulses and drawing a current at said constant rate into said second
9 integrated-circuit capacitor during an interval corresponding to said
10 prescribed interval.

1 5. A phase detector comprising:
2 a switching pulse source for receiving a first reference pulse of a
3 predetermined constant frequency and an input pulse and producing said
4 first charge timing pulse of duration corresponding to a phase difference
5 between said first reference pulse and said input pulse, for receiving a
6 second reference pulse of said predetermined constant frequency and



7 producing a second charge timing pulse of constant duration
8 corresponding to a phase difference between said first and second
9 reference pulses, and for successively producing a sampling pulse and a
10 discharge timing pulse during an interval following a trailing edge of said
11 first reference pulse;
12 first and second identical constant current sources;
13 a first capacitor;
14 first switch means for drawing a current from the constant current
15 source into the first capacitor in response to said first charge timing pulse
16 and drawing a current from the first capacitor in response to said discharge
17 timing pulse;
18 a first sample-and-hold circuit responsive to said sampling pulse for
19 sampling a voltage developed in the first capacitor and holding the
20 sampled voltage;
21 a second capacitor;
22 second switch means for drawing a current from the constant current
23 source into the second capacitor in response to said second charge timing
24 pulse and drawing a current from the second capacitor (8) in response to
25 said discharge timing pulse;
26 a second sample-and-hold circuit responsive to said sampling pulse for
27 sampling a voltage developed in the second capacitor and holding the
28 sampled voltage; and
29 means for detecting a voltage difference between the voltages
30 sampled by said first and second sample-and-hold circuits.



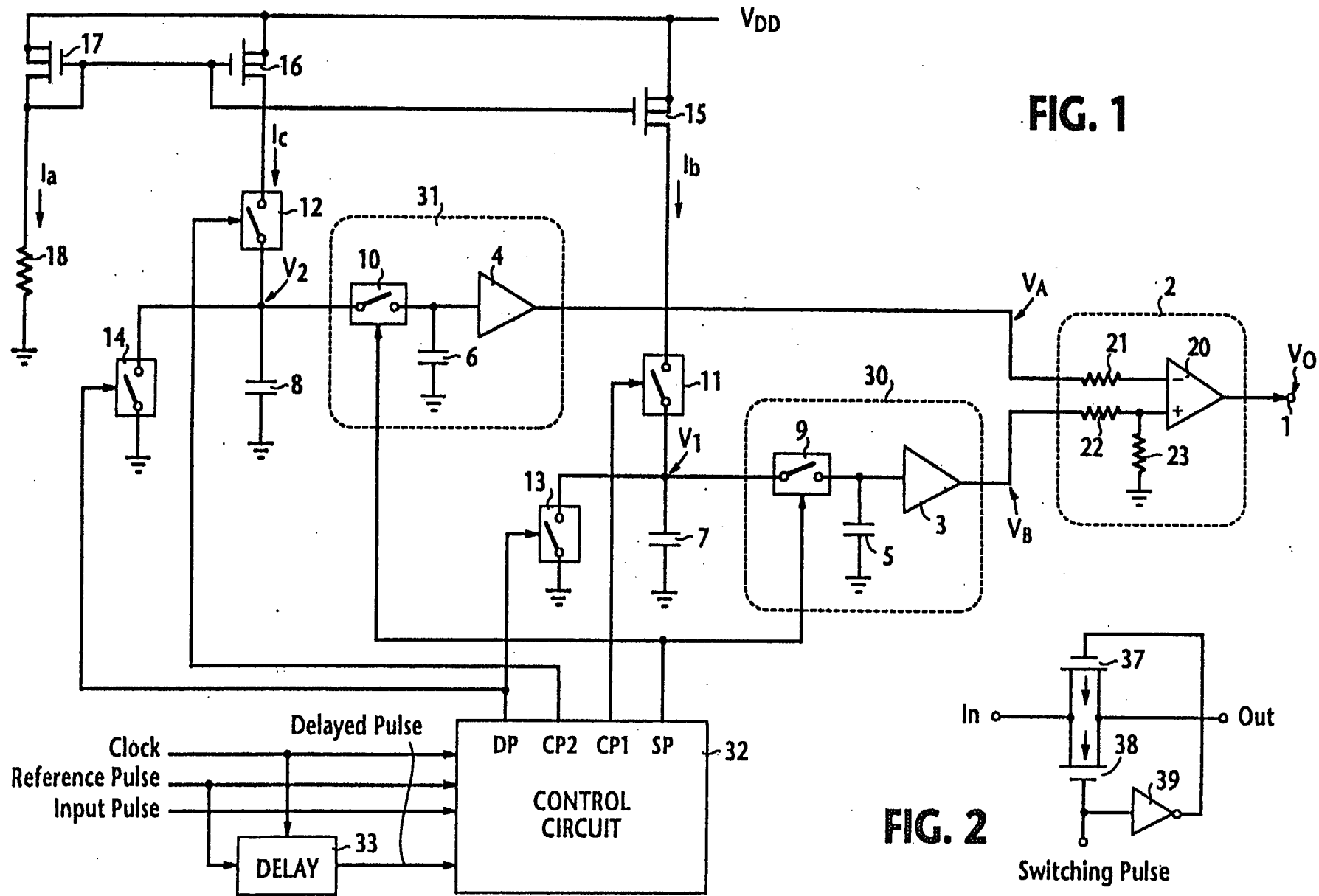
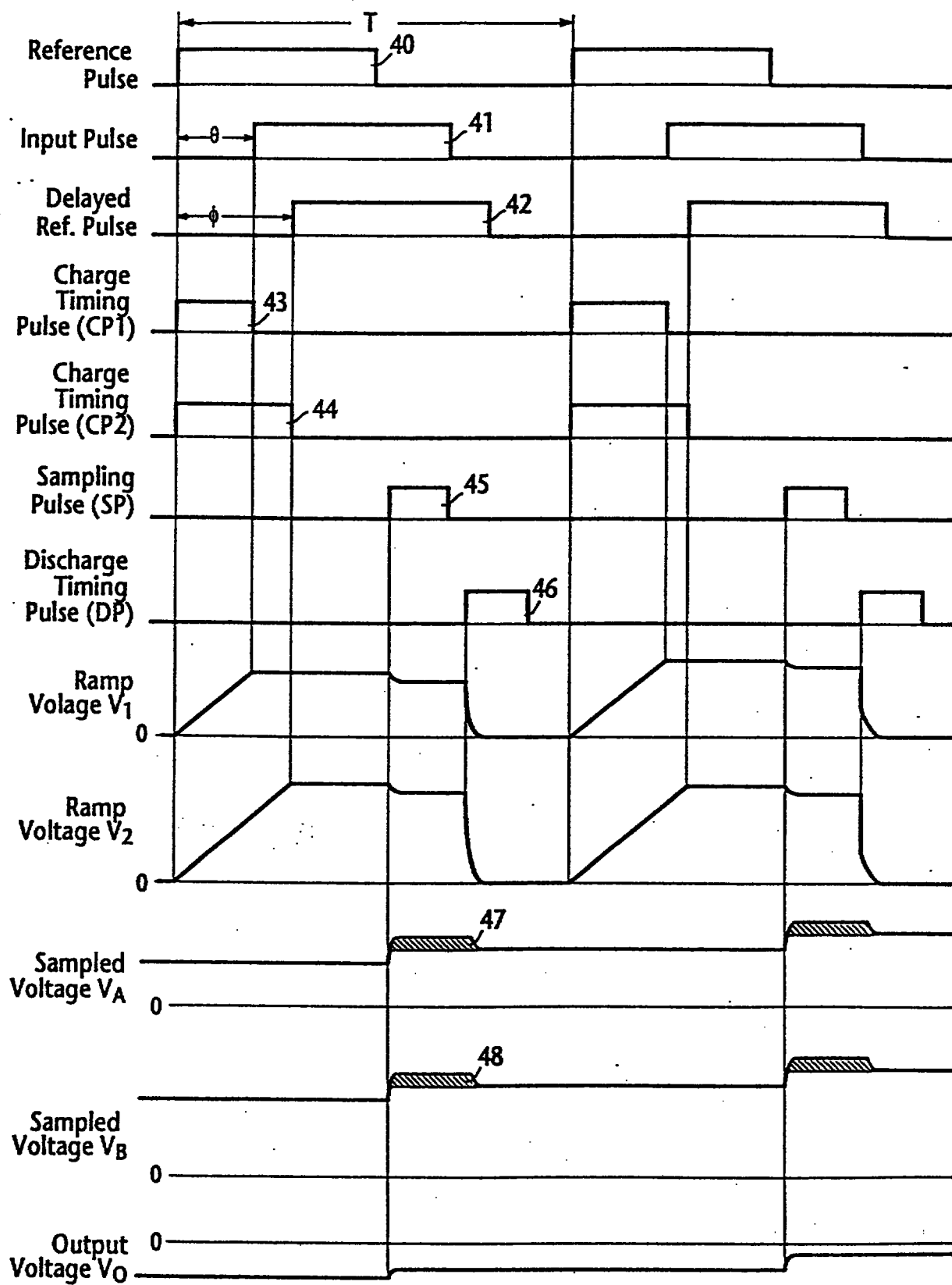


FIG. 3



RIPPLE-FREE PHASE DETECTOR USING TWO SAMPLE-AND-HOLD CIRCUITS

ABSTRACT

A phase detector comprises a ramp voltage generator for receiving a reference pulse of a constant frequency and an input pulse and producing a ramp voltage proportional to the phase difference between these pulses. A first sample-and-hold circuit (30) samples the ramp voltage in response to a sampling pulse and holds the sampled voltage. To eliminate ripple component, a second sample-and-hold circuit (31) is provided, which is also responsive to the sampling pulse for sampling a voltage from a constant voltage source and holding the sampled voltage. The voltages sampled by the first and second sample-and-hold circuits (30, 31) are input to a subtractor where the voltage difference between the two input voltages is detected. Ripple components generated by the two sample-and-hold circuits (30, 31) are cancelled out by the subtractor.

Fig. 1

