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A three phase function generator

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ABSTRACT

A variable frequency and variable phase function generator with three outputs of (1) reference f_O (2) lead phase $f_O + \varnothing_1$ and (3) lag phase $f_O - \varnothing_2$, is described in this paper. The leading phase difference $\varnothing_1$ is continuously adjustable over 0 to 180° by an input control voltage V_{C1} and the lagging phase difference $\varnothing_2$ is also continuously adjustable over 0 to -180° by an another input control voltage V_{C2}, independent of frequency of operation of the function generator which can be set by a third control input dc voltage $-V_I$.

Introduction

Function generators with reference and phase shifted outputs are essential to design and test modern instrumentation and control circuits. An example is the phase sensitive detector [1] that plays an important role in impedance measurement, power measurement, instrument transformer error measurement etc. A conventional method of testing phase sensitive detectors and phase measuring circuits is with a sine wave generator and an additional phase shifter. In this method an all pass filter obtains the phase difference θ between the two outputs. If the frequency of the sine wave changes then the phase difference is modified and θ also changes when there is a change in the value of R and C due to their tolerances.

A variable frequency fixed phase sequence was developed by [2] consists of astable multivibrator, and a divide by three logic network followed by a divide by two logic network with a synchronizing gate. In this method variable phase sequence can't be obtained. A method by [3] was developed in which millimeter wave signal of phase shift 0 to 360 degrees is generated for a constant frequency only. It would be highly beneficial to have a phase difference between the outputs is precisely controllable and independent of the frequency of operation and drift in the component values. A variable frequency and variable phase function generator with dual outputs [4] is useful only for dual phase applications. An improvement on this circuit [4] as three phase function generator for three phase applications is explained in this paper.

Circuit Analysis

The circuit diagram of the proposed three phase function generator is shown in Fig. 1 and its associated waveforms in Fig. 2. A sawtooth wave with peak value V_R is generated by opamps OA1,OA2 and a switch SW1. Let us assume that at start, the charge and hence voltage at the output terminal of opamp OA1 is zero. Since the inverting terminal of the opamp OA1 is at virtual ground, the current through R, namely V_I/R amps, would flow through and charge the capacitor C. During the capacitor being charged (till the output of OA1 reaches a voltage level of V_R) the output of opamp OA2, configured to work as comparator, will be at the LOW state and switch SW1 is kept open (OFF). As soon as the output of OA1 crosses the level of V_R, say after a time period T, the output of comparator OA2 goes high and the switch SW1 is closed (ON). The switch SW1 would then short the capacitor C and hence the output of integrator OA1 Vs drops to zero volts. During the time period T we have,

$$Vs = \frac{1}{RC}\int V_I\,dt = \frac{V_I}{RC}t \qquad (1)$$

After a very short delay time Td, required for the capacitor to discharge to zero volts, the comparator output returns to LOW and switch SW1 is opened, thus allowing C to resume charging. This cycle, therefore, repeats itself at a period (T+Td). From the equation (1) and the fact that at time t = T, Vs = V_R, we get

$$T = \frac{V_R}{V_I}RC \qquad (2)$$

A short pulse V_{P1} is generating at the output of comparator OA2 and is given to a toggle flop FF A. A square wave 'X' of period 2T is obtained at the output of toggle flip FF A. This wave is called as reference square wave. The sawtooth waveform V_S generated at the output of integrator OA1 is compared with a control voltage V_{C1} by the comparator OA3, a rectangular waveform V_{P2} whose OFF time is proportional to the control voltage V_{C1} is obtained at the output of comparator OA3 and is given to the toggle flip flop FF B. The output of this toggle flip flop FF B is a square wave 'Y' of period 2T and this wave is called phase lead square wave.

$$\text{Lead phase difference } (\varnothing_1) = \frac{V_{C1}}{V_R}\,180^o \qquad (3)$$

The sawtooth wave Vs is also compared with another control voltage V_{C2} by the comparator OA4. A rectangular waveform V_{P3} whose OFF time is proportional to the voltage V_{C2}, is generated at the output of comparator OA4 and is given to the toggle flip flop FF C.

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Fig. 1 Circuit diagram of three phase function generator

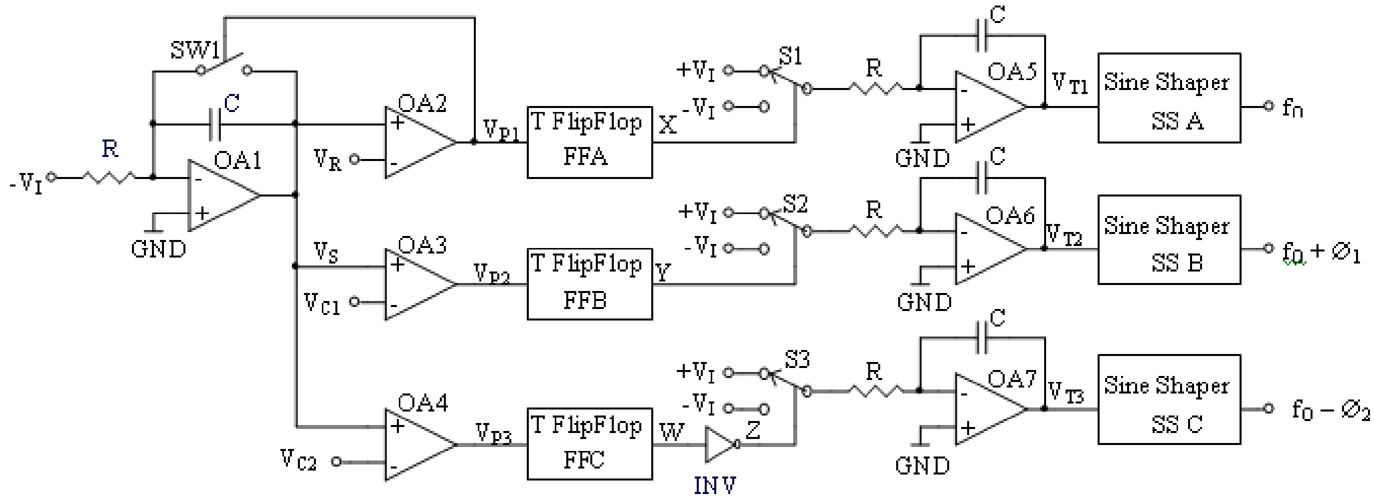
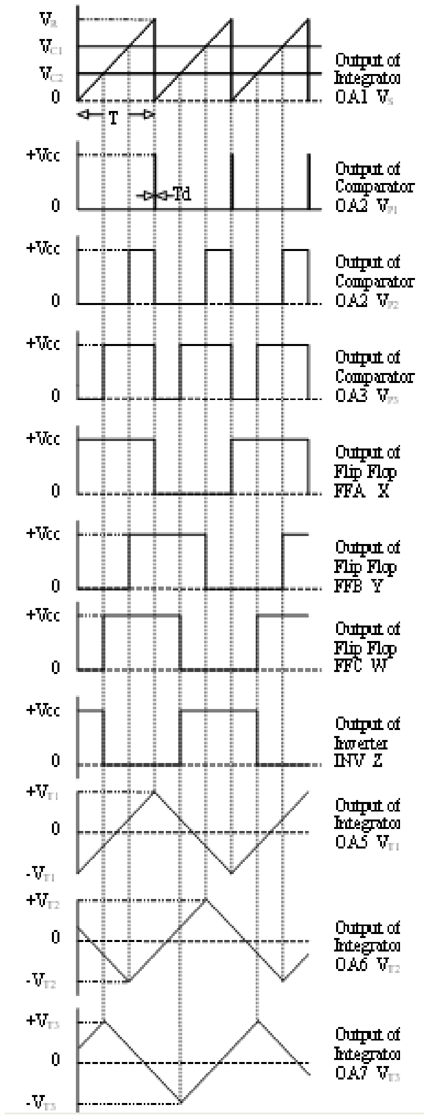


Fig. 2 Associated waveforms of Fig. 1



The output of this toggle flip flop is a square wave 'W' of period 2T and is inverted by inverter INV and the inverted square wave 'Z' is called lag phase square wave.

$$\text{Lag phase difference } (\varnothing_2) = -\frac{V_{C2}}{V_R} 180^o \quad (4)$$

The reference triangular wave V_{T1} is generated by the switch S_1 and the integrator OA5. The ON time of reference square wave 'X' selects $-V_I$ through the switch S_1 to the integrator OA5. The output of the integrator OA5 will be

$$V_{T1}(t) = \frac{1}{RC}\int V_I\,dt = \frac{V_I}{RC}t + Vt(0) \quad (5)$$

where Vt(0) is the initial voltage at t = 0. Let us assume Vt(0) = $-V_T$. At t = T, $V_{T1}(t) = +V_{T1}$

$$V_{T1} = \frac{V_I}{RC}T - V_{T1}$$

$$V_{T1} = \frac{V_R}{2} \quad (6)$$

The OFF time of the square wave 'X' selects $+V_I$ through the switch S_1 to the integrator OA5. Its output will be

$$V_{T1}(t) = \frac{1}{RC}\int -V_I\,dt = -\frac{V_I}{RC}t + Vt(0) \quad (7)$$

Where Vt(0) is the initial voltage which is now + V_{T1} , at t = T,

$$V_{T1}(t) = -V_{T1} = -\frac{V_R}{2} \quad (8)$$

Hence a reference triangular waveform is generated at the output of integrator OA5 with peak to peak value of $\pm V_{T1}$ or $\pm V_R/2$). In similar way (1) phase lead triangular wave V_{T2} with peak to peak value of $\pm V_{T2}$ from the phase lead square wave 'Y' is generated at the output of the integrator OA6 by the switch S_2 and (2) phase lag triangular wave V_{T3} with peak to peak value of $\pm V_{T3}$ from phase lag square wave 'Z' is generated at the output of integrator OA7 by the switch S_3. The reference sine wave f_O is converted from the reference triangular wave V_{T1} by the sine shaper SS A [5]. In similar way (1) phase lead sine wave $f_O + \varnothing_1$ is converted from phase lead triangular wave V_{T2} by the sine shaper SS B and (2) phase lag sine wave $f_{O} - \varnothing_2$ is converted from the phase lag triangular wave V_{T3} by the sine shaper SS C.

Experimental Results

The proposed circuit diagram was wired and tested in our Laboratory. OP 07 IC was used for all opamps. CD 4016 IC was used for switch SW1 and CD 4053 IC was used for the other switchs S_1- S_3. CD 4013 IC was used as T Flip Flops. A power Supply of ±Vcc = ±7.5V was chosen for the circuit. LM 336 2.5V voltage reference was used for V_R. ie V_R = 2.5V. R = 1MΩ 1% resistors were chosen. V_{C1} and V_{C2} were kept constant voltage of 1V and $-V_I$ was varied from 0.5V to 5V by selecting C as 10nF, 1nF and 100pF for three decade ranges. The waveforms in the circuit were observed in Philips PM 3206 Dual Trace CRO and verified as given in Fig. 2. The output frequency was measured with HIL 2722 universal counter. The readings were taken. Then Frequency was kept constant ($-V_I$ = 2.5V, C = 10nF), V_{C1} was varied from 0.1V to 2.4V, the time delay between the reference and lead phase square waves was measured in HIL 2722 universal counter. Then V_{C2} is varied from 0.1V to 2.4V, the time delay between the reference and lag phase square waves was measured in HIL 2722 universal counter. The readings were taken. It is observed from the readings that the (1) Frequency Error in the range 10Hz - 100Hz = 0.5%, 100Hz - 1KHz = 1% and 1KHz - 10KHz = 2% (2) Phase error in all frequency ranges is found to be less than 0.1%.

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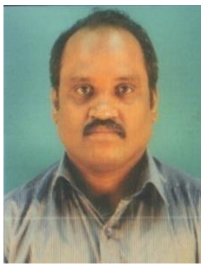
Authors Profile



K.C. Selvam was born on 2nd April 1968 in Krishnagiri District of Tamil Nadu State, India. He was graduated by the Institution of Electronics and Telecommunication Engineers, New Delhi, in the year 1994. He has published 14 research papers in various national and international journals. He got best paper award by IETE in the year 1996. At present he is working as Technical Staff in the Department of Electrical Engineering, Indian Institute of Technology, Madras, India. He developed interest in Measurement and Instrumentation systems.