Amplitude Control of Twin-T and Phase-Shift Oscillators Based on Direct Feedback Control Technique

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ABSTRACT

This article presents a simple circuit design for control the amplitude value of the Twin-T and the Phase-Shift oscillators. The proposed circuit design uses feedback control technique to control the oscillator directly without multiplier circuit. The structure of the designed system consists of a target oscillator, an offset eliminator, an amplitude detector, and an error integrator to generate direct current-type (DC) voltages of the target oscillator. Both the Twin-T and the Phase-Shift oscillators can adjust amplitude value by using an external control signal. Experimental results verifying performance of the designed circuit by using direct feedback control technique agreed with expected values.

Keywords: Oscillator, amplitude control, feedback control, second-order oscillator, multi-time variable technique.

INTRODUCTION

A sinusoidal signal oscillator is a useful circuit building block in electronics, instrumentation and measurement systems. It is used in form of the excitation signal generators for some tested circuits, sensors, and transducers (Kaewpoonsuk *et al*., 2008; Chen *et al*., 2011; Bera and Chakraborty, 2009; Rerkratn *et al*., 2007). In addition, it also plays as a carrier signal generator role in control and communication systems (Margarit *et al*., 1999; Schuler, 2013). The traditional realization of a sinusoidal signal generator was implemented by using a triangular signal generator connected with a triangular-to-sine waveform converter (Jacob, 1993; Franco, 1998). This method provides an easy amplitude control of the generated signal. The accuracy of this approach is strongly dependent on the performance of the waveform converter circuit. Moreover, it also causes the large size topology. The sinusoidal oscillator based on second-order differential equation technique can directly generate sinusoidal waveform signal. However, the amplitude control of the signal is difficult. One fundamental approach for implementing an amplitude control of the sinusoidal signal oscillator is based on feedback control technique (Hou, 2005;

Filanovsky and Fortier, 1985). It requires a multiplier for the functional circuit building block. This approach has a great disadvantage in the topology of the scheme, and it is the cost for realization. Recently, the circuit analysis of sinusoidal signal oscillators based on multi-time variable technique is presented (Maneechukate *et al*., 2008). It has been demonstrated that the amplitude value of sinusoidal signals from three important oscillators; Twin-T, Phase-shift, and Wien bridge oscillators, is dependent on the external bias voltages. However, the relationship between the amplitude value and the external bias voltage is not the positive slope and it has an offset component in the output signals. In 2013, an improved Wien bridge oscillator with variable output amplitude value is introduced (Kaewpoonsuk *et al*., 2013). This approach is based on the feedback control technique without multiplier requirement. To complete this concept, the other two sinusoidal signal oscillators, Twin-T and Phase-shift, are investigated in this paper.

CONCEPT AND DESIGN TECHNIQUE

Twin-T and Phase-Shift Oscillators

The general schemes of the Twin-T and the Phase-shift oscillators are shown on the left side in figure 1. The proposed oscillators use the operational amplifier (Op-amp) A_1 as basic building block. According to the suitable conditions and the conventional analysis of each circuit used, both oscillators provide the sinusoidal signals V_{os} with oscillation frequency f_{os} as

$$f_{os} = \frac{\omega_{os}}{2\pi} = \frac{1}{2\pi}\begin{cases} 1/RC & \text{for Twin-T oscillator} \\ 1/RC\sqrt{6} & \text{for Phase-Shift oscillator} \end{cases} \tag{1}$$

Hence, the amplitude values of both generated signals are fixed at the saturation output voltage of the Op-amps used. The Twin-T and the Phase-Shift oscillators with external DC voltage V_B using the multi-time variable technique are shown on the right side in figure 1. In the case of V_B>0V, the generated signals of both circuits can be stated as equation (2)

$$V_{os} = -A_{os}\cos(2\pi f_{os}t) + V_{offset} \tag{2}$$

where

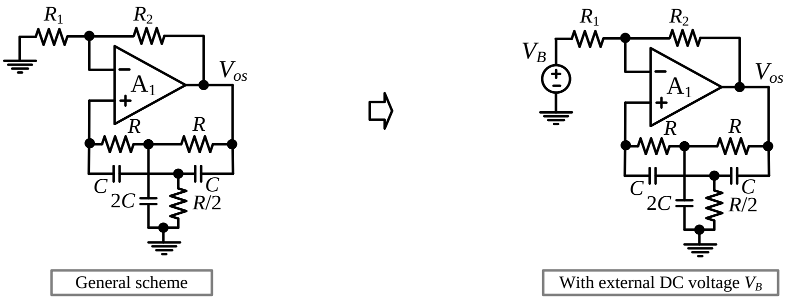
$$A_{os} = \begin{cases} V_{sat} - V_B & \text{for Twin-T oscillator} \\ V_{sat} - 29V_B & \text{for Phase-Shift oscillator} \end{cases} \tag{3}$$

$$f_{os} = \frac{\omega_{os}}{2\pi} = \frac{1}{2\pi}\begin{cases} 1/RC & \text{for Twin-T oscillator} \\ 1/RC\sqrt{6} & \text{for Phase-Shift oscillator} \end{cases} \tag{4}$$

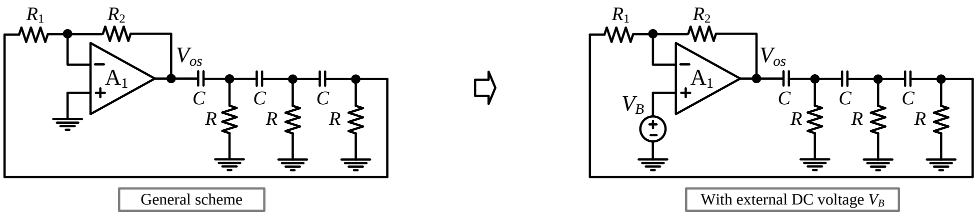
and

$$V_{offset} = \begin{cases} V_B & \text{for Twin-T oscillator} \\ 29V_B & \text{for Phase-Shift oscillator} \end{cases} \tag{5}$$

Note that we can control the amplitude value of the sinusoidal signals V_{os} with the DC voltage V_B which can be adjustable. However, there are not direct variations but are inverse relations. In addition, the signals V_{os} comprise of the offset terms V_{offset}.



(a) Twin-T oscillator



(b) Phase-Shift oscillator

Figure 1 Twin-T and Phase-Shift oscillators

Proposed technique

The improved amplitude control system of the Twin-T and the Phase-Shift oscillators based on direct feedback control technique is shown in Figure 2. It consists of a target oscillator, an offset eliminator, an amplitude detector, and an error integrator. The signals V_C and V_{out} denote the external control voltage and the sinusoidal output signal of the system, respectively. The Op-amp A_2 acts as the offset eliminator which removes the offset term from the oscillator signals V_{os} of each oscillator. The suitable conditions such as $R_3=R_4=R_5=R_6$ and $R_4=R_5=29R_3=29R_6$ were set in offset eliminator for the Twin-T and the Phase-Shift oscillators, respectively. Therefore, the output voltage signal V_{out} can be stated as

$$V_{out} = -A_{os}\cos(\omega_{os}t) \tag{6}$$

where

$$A_{os} = \begin{cases} V_{sat} - V_B \\ V_{sat} - 29V_B \end{cases} \tag{7}$$

and $$\omega_{os} = \begin{cases} 1/RC & \text{for Twin-T oscillator} \\ 1/RC\sqrt{6} & \text{for Phase-Shift oscillator} \end{cases} \tag{8}$$

The amplitude value of output signals V_{out} is detected by the amplitude detector which designs by using Op-amp A_3. The amplitude value of V_{out} is DC voltage V_A as

$$V_A = A_{os} \tag{9}$$

The Op-amp A_4 is used to design the error integrator. The voltage signal V_A is compared with the external control signal V_C. If $V_A = V_C$, the error integrator holds its output voltage V_B. Whenever the value of V_A and V_C is different, this different value is integrated to produce the new value of V_B. From routine circuit analysis, the relation of the voltage V_A, V_C, and the amplitude value (A_{os}) of the output signal V_{out} can be expressed as

$$V_A = A_{os} = \frac{2R_{12}}{R_{11} + 2(R_{12} + R_{11})} V_C + \frac{R_{11}}{R_{11} + 2(R_{12} + R_{11})} V_{sat} \tag{10}$$

If we let $R_{12} >> R_{11}$, then equation (10) can be approximated as

$$V_A = A_{os} = V_C \tag{11}$$

From equation (11), it is clearly seen that the amplitude value of V_{out} can be directly controlled by the external voltage signal V_C.

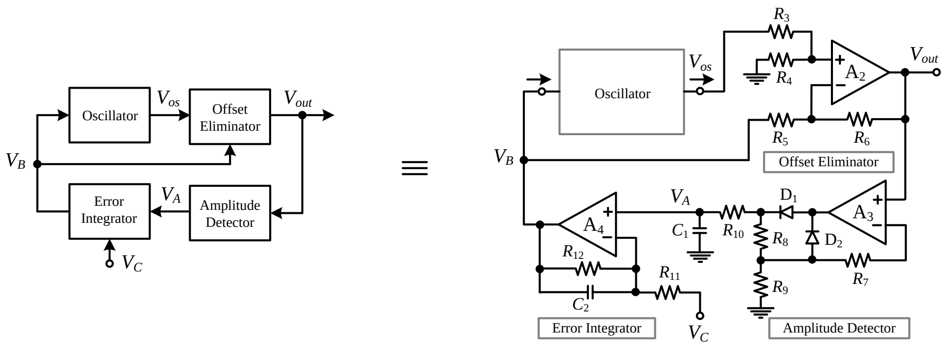
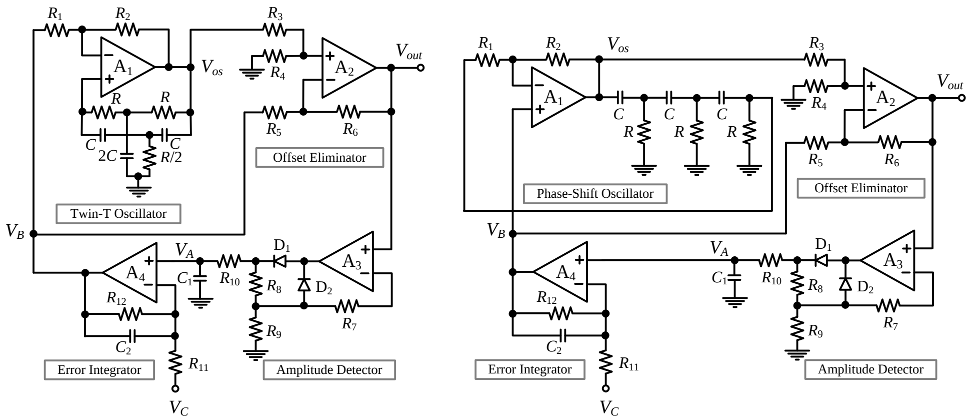


Figure 2 Proposed amplitude control circuit of Twin-T and Phase-Shift oscillators

DESCRIPTION OF THE DESIGNED CIRCUITS

The performance of the proposed technique has been confirmed by hardware implementations on a breadboard. The figure 3(a) shows the improved Twin-T oscillator with variable output amplitude using Op-amps UA741, diodes 1N4148, capacitors and resistors. The supply voltages are ±10V, while the values of device components are: $R = R_{11} = 1$ kΩ, $R_1 = 50$ kΩ, R_2 to $R_7 = R_{10} = 10$ kΩ, $R_8 = R_9 = R_{12} = 100$ kΩ, $C = C_1 = 0.1$ µF, and $C_2 = 10$ µF. Hence $f_{os} = 1.59$ kHz can be achieved.

Another oscillator is improved. It is shown in figure 3(b) which is the Phase-Shift oscillator with the variable output amplitude. The Phase-Shift oscillator circuit uses the Op-amp UA741 like the Twin-T oscillator circuit but the used values of device components are different which are: $R = 500$ Ω, $R_1 = R_3 = R_6 = R_9 = R_{12} = 100$ kΩ, $R_2 = 50$ kΩ, $R_4 = R_5 = 2.2$ kΩ, $R_7 = 10$ kΩ, $R_8 = 500$ kΩ, $R_{10} = 100$ Ω, $R_{11} = 1$kΩ, $C = C_1 = 0.1$ µF, and $C_2 = 33$ µF. Hence $f_{os} = 1.30$ kHz can be achieved. In order to test the Twin-T and the Phase-Shift oscillators, the control voltages V_C having frequency of 1 Hz for sinusoidal waveform are applied. In addition, the control amplitude value of V_{os} is provided by varying external voltage V_C in range of 0-5 V.

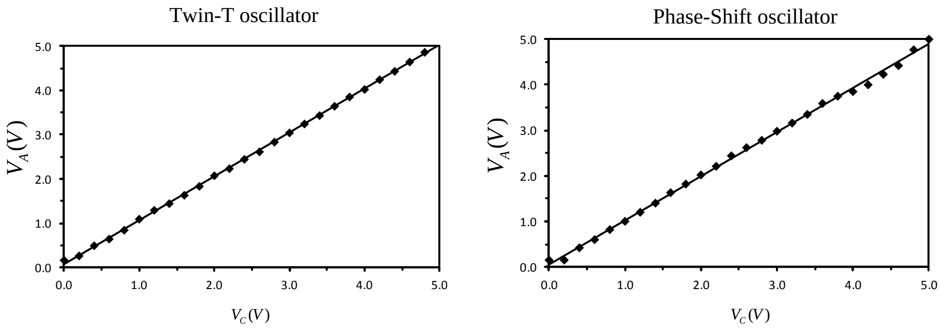


(a) Twin-T oscillator (b) Phase-Shift oscillator

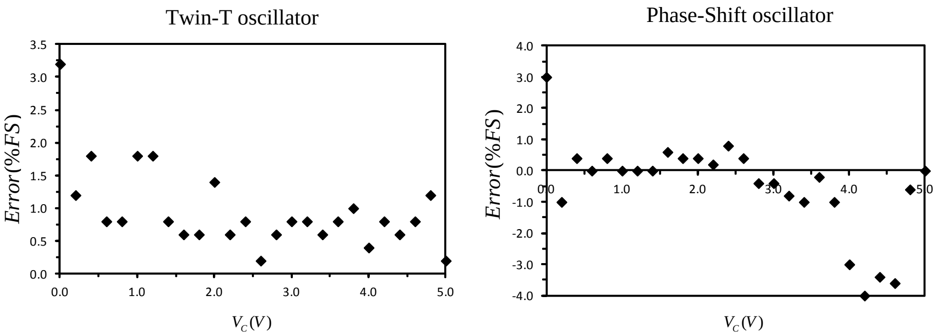
Figure 3 Improved oscillator circuits with variable output amplitude

EXPERIMENTAL RESULTS AND DISCUSSION

The measured results of the voltage V_A versus V_C are plotted for determining DC transfer characteristic of both proposed oscillators. These results are displayed in figure 4(a) which is obvious that the relations of the output amplitude values V_A and the external voltages V_C are linear. The figure 4(b) illustrates plots of non-linearity error versus V_C. The maximum non-linearity errors of the Twin-T and the Phase-Shift oscillators are about 200 mV (or 4 %) and 170 mV (or 3.4 %) of full scale range, respectively.



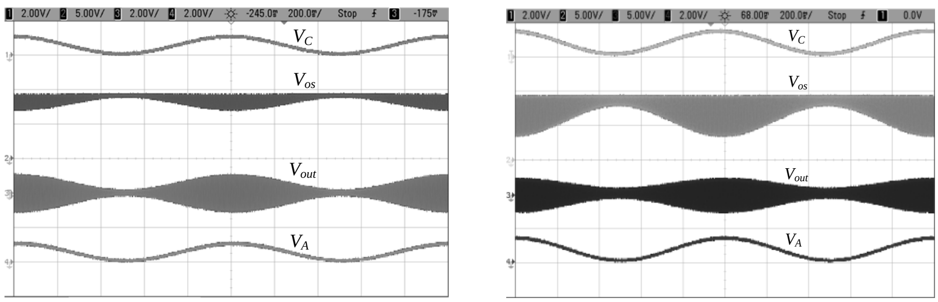
(a) DC transfer characteristic



(b) Non-linearity errors

Figure 4 Measured results for varying V_C in range of 0-5 V

However, the accuracy can be expected if the accurate amplitude detector is improved further (Maneechukate *et al*., 2008). The figure 5 shows the signals (V_C, V_{os}, V_{out}, and V_A) of both oscillator circuits. Those signals are the results obtained from applying V_C in sinusoidal waveform having frequency of 1 Hz. It can be seen that all measured waveforms agree well with the expected values.



(a) Twin-T oscillator (b) Phase-Shift oscillator

Figure 5 Measured results from applying V_C having frequency of 1 Hz

CONCLUSION

The Twin-T and the Phase-Shift oscillators are improved using commercially available devices and only Op-amp as active elements. The output amplitude value of both oscillators can be variable. The proposed technique in this article utilizes the offset eliminator, amplitude detector, and error integrator connecting with the external control voltage. From experimental results, it is evident that the proposed oscillators work correctly and agree very well with the expected values. Moreover, the structure of both sinusoidal oscillators has been simply designed.

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