Amplitude Control in a Triangular Wave Quadrature Oscillator

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Abstract

The simple circuits that have been usually reported as triangular wave quadrature generators are based on conservative equations that do not properly describe the starting transient and the amplitude stabilization mechanism. As it has been shown in a previous work, the slew-rate of the operational amplifier and the limited output voltage of the integrator are responsible for the starting and the stabilization of the generated waveforms. As an extension of this work, in this communication, a new simple circuit for generating triangular waves in quadrature is proposed. This circuit allows both obtaining the correct quadrature between the triangular waves and controlling their amplitude. This amplitude control is accomplished by the variation of a relation between resistors, thus allowing electronic control. Simulation results show good agreement with theoretical predictions.

1.Introduction

A triangular wave quadrature oscillator consists essentially of a chain of integrators and comparators [1]-[2], as it is shown in the circuit of Figure 1.

Although there are not initial conditions on the circuit signals, the integrator outputs (variables x_2 and x_4) grow from a practically zero initial value (on the order of magnitude of circuit noise) to a final value given by the limited voltage at the integrator outputs. The start-up of the generator, as explained in [3], is given by the *slew-rate* of the comparators the effect of which can be seen as a delay in the circuit dynamics. This delay is determined by the finite time that the output of the comparator takes to change from one value to another. This delay is responsible for the fact that the triangular waves are no exactly in quadrature (the zero value of one of the signals is not coincident with the maximum value of the other triangular wave). Figure 2 shows the phase plane trajectory of the integrators output signals of the circuit in Figure 1 (signals x_2 and x_4) during the start-up. It can be observed that the rectilinear trajectory that ideally must perform the two triangular waves becomes a parabolic trajectory every time that one of the comparators changes its output (for example, time intervals from t_1 to t_3 and from t_4 to t_6).

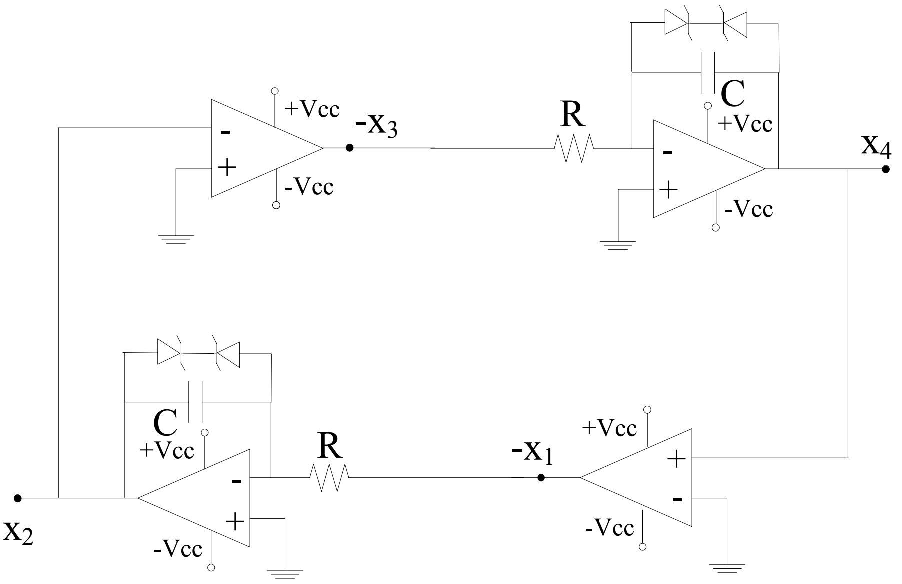

Figure 1. Circuit diagram of a triangular wave quadrature oscillator.

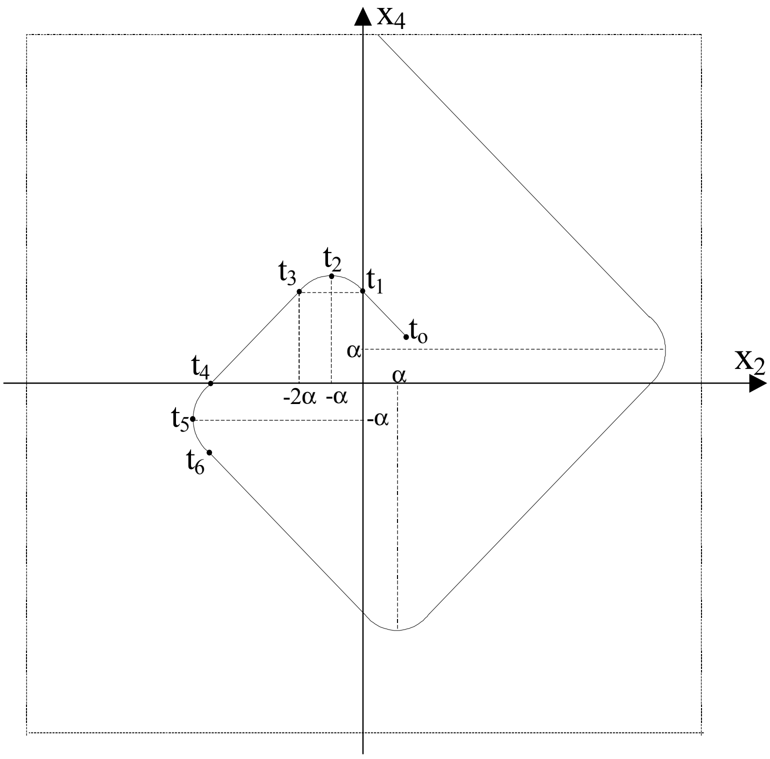

Figure 2. Phase-plane trajectory for start-up.

The *slew-rate* effect can be seen as an effective delay between the moment in which one of the triangular signals reaches the zero value (instant t_1 on the first transition of the trajectory in Figure 2) and the moment in which the other triangular wave reaches the maximum value (t_2 in the same transition). This effect not only influences the fact that the triangular signals are not in quadrature, but is also responsible for the amplitude growth as can be observed in Figure 2.

The value of the parameter α in Figure 2 is given by [3]:

$$\alpha = \frac{\omega (Vsat)^2}{SR} \tag{1}$$

where ω=1/RC is the integration constant, *Vsat* is the output voltage of the comparators and *SR* is the *slew-rate* of the operational amplifier.

The delay introduced by the comparators, if the parabolic behavior is neglected, is equivalent to that introduced by an ideal comparator with levels -α, or α, depending whether the input signal is positive or negative. α (or -α) is the value of one of the triangular waves when the other reaches the maximum value in one cycle. In order to compensate the effect of this delay and then obtain the stabilization of the signal amplitude, an additional comparison level can be introduced in the comparator. The threshold level externally introduced must compensate the α value when the amplitude of the triangular wave has reached the desired value. However, during the start-up this level must be smaller than that given by the *slew-rate*, so that this process continues being the responsible for the start-up of the oscillator. The proposed circuit that allows modifying the comparison level in function of the amplitude of the triangular waves is shown in Figure 3.

Resistors R_1, R_2 in each of the comparators relate the level of comparison with the amplitude of the triangular waves (the integrator outputs). When the amplitude of the triangular waves provides a level of comparison through those resistors that compensates the delay imposed by the *slew-rate* of the comparator, the amplitude of the triangular waves becomes stable. This threshold level of comparison is just the value α in equation (1).

Thus, in order to design a circuit in such a way that the amplitude of the triangular waves reaches value A_Δ in the steady-state, the value of resistors R_1 and R_2 must be chosen in order to fulfill the following expression

$$\frac{R_2}{R_1} = \left(\frac{A_\Delta}{\alpha} - 1 \right) \tag{2}$$

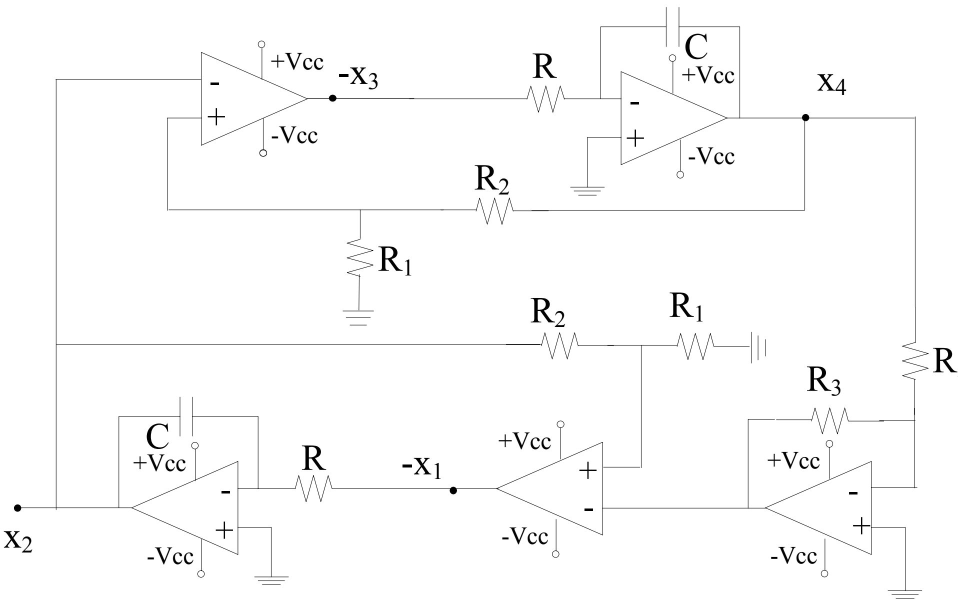

Figure 3. Proposed circuit for the amplitude control in a triangular wave quadrature generator.

3. Simulation results

In order to show an example of design, the proposed circuit of Figure 3 has been simulated. The value of elements R and C have been chosen to obtain an integration constant ω of 200 rad/s. From equation (1) and taking into account the characteristics of the typical AO 741 used for simulation, a value α=140 mV has been calculated. From equation (2) the necessary value for resistors R_1 and R_2 has been obtained for a final amplitude value of 1.4 V for the triangular waves.

In Figure 5 the simulation results obtained for a pair of different values of resistors R_1 and R_2 are presented. In this case the ratio R_2/R_1 was lower, then the final amplitude of the triangular waves reached a higher value (6 V).

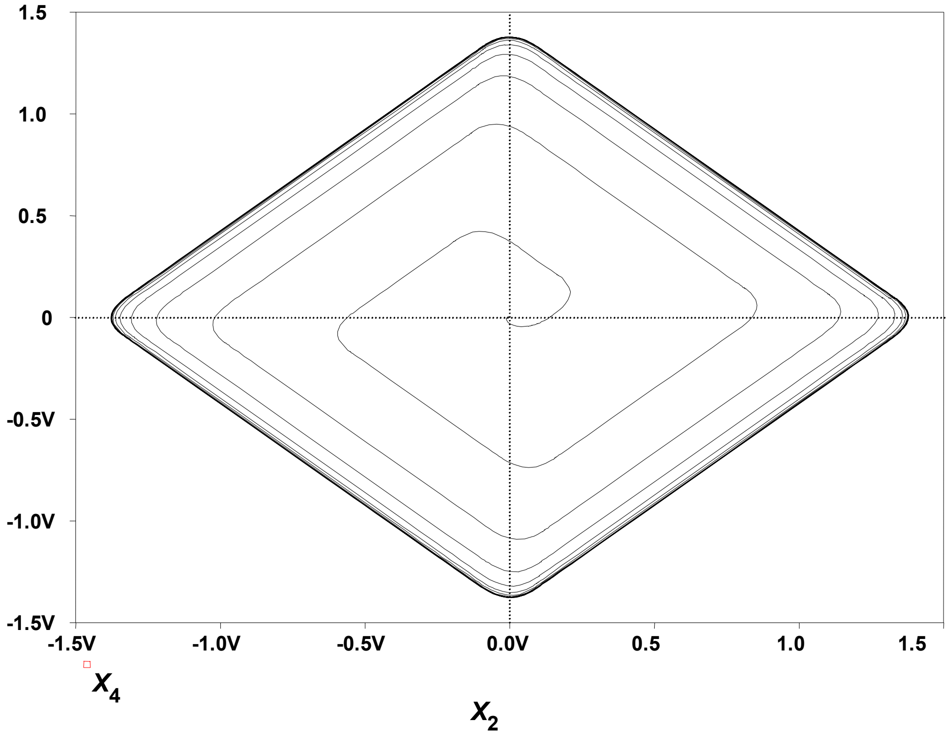

Figure 4. Phase-plane trajectory for start-up and steady state of signals x_4 and x_2 in Figure 3.

In Figure 4 and 5, the start-up and the steady state phase plane trajectory of signals x_2 and x_4 in Figure 3 for two different designs can be seen. During the start-up the delay introduced by the *slew-rate* of the operational amplifier is responsible for the amplitude growth of the signals and the signal shape as it is explained in Figure 2. During this start-up the zero value of a signal does not coincide with the maximum value of the other triangular wave. As the amplitude of the signals grows, the threshold level given by resistors R_1 and R_2 in Figure 2 also grows, compensating a part of the delay introduced by the *slew-rate*. When the level introduced by those resistors totally compensates the delay introduced by the *slew-rate*, the quadrature between the triangular waves x_2 and x_4 is accomplished and the steady state is reached as it can be observed in the two figures 4 and 5.

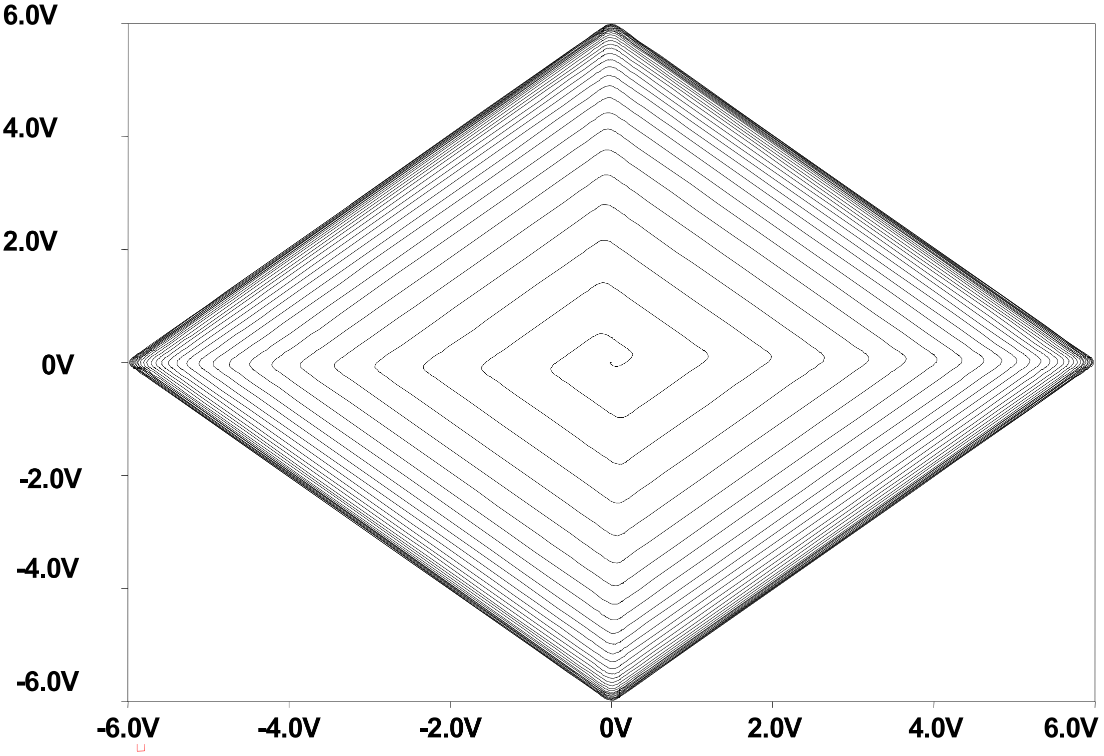

Figure 5. Phase-plane trajectory for start-up and steady state of signals x_4 and x_2 in Figure 3.

4. Conclusions

The proposed circuit allows controlling the amplitude of the generated triangular waves, compensating the delay introduced by the *slew-rate* of the operational amplifier, and improving the quadrature behavior that normally gives the typical configuration. The amplitude control of the triangular waves is accomplished by the variation of a relation between resistors, thus allowing electronic control of this amplitude [4]-[5].

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References

[1] B.Z. Kaplan, D. Har-Zahav, A. Blau, *'A Simple Quadrature Oscillator for Generating Triangular Waves and Square Waves'*, Proc, IEEE, Vol.67, No.11, November 1979, pp.1566-1567.

[2] J.R. Pimentel, *'Analysis and Synthesis of Waveform Generators in the Phase Plane'* IEEE Trans. On Industrial Electronics and Control Instrumentation, Vol. IECI-25, No.3, August 1978, pp. 217-220

[3] E. Vidal, A. Poveda, E. Alarcón, *'Amplitude Stabilization in a Triangular Wave Quadrature Oscillator'* Proc. of the Midwest Symposium on Circuits and Systems, Ames, Iowa, 1996, pp. 1083-1086.

[4] Yannis P. Tsividis, *'Integrated Continuos-Time Filter Design- An Overview'*, IEEE Journal of Solid-State Circuits, Vol. 29, No.3, March, 1994, pp. 166-176.

[5] X.D.Jia, R.M.M.Chen, *'Simulation and Design of Continuous-Time Mosfet-C Oscillator Circuits'*, IEEE Int. Conference on Microelectronics and VLSI (IEEE TENCON), 1995, pp. 355-358.