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Design of Integrator and Comparator based on Digital Integrated Circuits

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Abstract:

This article discusses the design method of integrator and comparator based on digital integrated circuits and circuit simulation using multisim is used to prove the functionality and performance of the circuits. By studying the advantages of digital circuits a circuit module has been designed which can realize integrator and comparator. This paper describes in detail the functioning and designing steps of the circuit and shows the results after simulation. The advantages, disadvantages and application cases of the design are analyzed through the simulation results. The simulation results show that it can fulfill the needs of various scenarios well.

Keywords: Integrator; Comparator; Multisim Simulation.

1. Introduction

With the development of electronic technology, digital integrated circuits occupy an important place in modern electronic systems, especially in the fields of signal processing and control systems. In the design of electronic system, integrator and comparator are the basic originals which are indispensable in the realization of signal processing and control system. Integrators convert input signals into output signals by means of operational amplifiers and feedback capacitors and are used in fields such as filters and analog computation. The comparator compares the input signal with the reference voltage by means of an operational amplifier and is used in such fields as voltage detection. With the continuous development of modern electronics, how to make these devices more efficient has become a major concern nowadays [1,2]. In this article, we are mainly discussing the design methodology of integrators and comparators based on operational amplifiers and feedback circuits, analyzing their roles in the circuits, and proving the effectiveness of their roles through theoretical calculations and simulations. The first chapter of the paper is the introduction, which firstly introduces the research background and research significance of the paper, the second chapter is the design of the comparator, the nature of the comparator is derived through theoretical analysis, and then the theoretical results are verified through multisim simulation, the third chapter is the design of the integrator, which introduces the role of the integrator and the principle of the design and carries out a theoretical analysis of the integrator, determines the different waveforms after the input of output waveforms situation, and then the theoretical situation is verified by multisim simulation. The last chapter is the conclusion, which is a summary of the whole paper.

2. Comparator

2.Design of the comparator

Function: The function of a comparator is to transform an arbitrary periodic waveform into a digital signal called a square wave. This is the most common method of converting analog signals into digital signals.

Design Methodology: Apply the principle that an ideal operational amplifier operates in the nonlinear region, which means that the signal is not amplified by an operator but instead it uses feedback or employs positive feedback so that it outputs a high level or a low level. Use this design idea to design a hysteresis comparator.

Principle Of Operation: Hysteresis comparator is a comparator circuit with hysteresis characteristic, when the input signal is close to the threshold voltage, the circuit does not switch the form immediately but introduces a hysteresis interval. This characteristic determines the input signal small changes will not cause changes in the output signal must be a large change in order to cause changes in the signal, thus improving the circuit's anti-interference ability and stability.

2.1 Fabrication

2.1.1 Operational Amplifier

Used to compare the size of the input signal with the reference signal [3] .The schematics are in Fig. 1 and Fig. 2

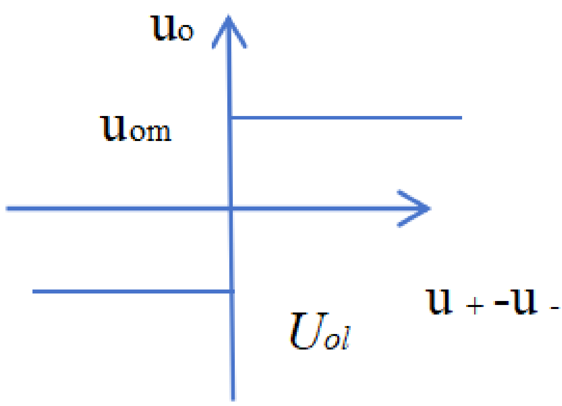

Fig. 1 Characteristics of operational amplifiers

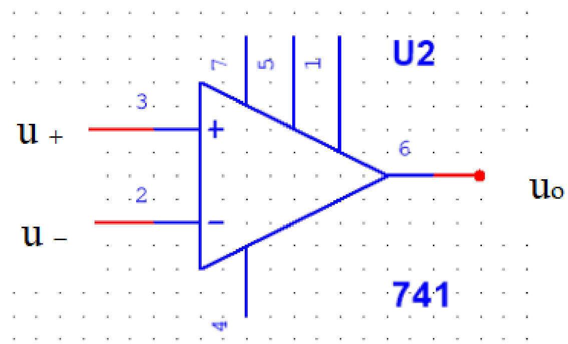

Fig. 2 Operational amplifier

2.1.2 Feedback Network

Consists of a resistor, which is responsible for introducing negative feedback to realize hysteresis effects [4].

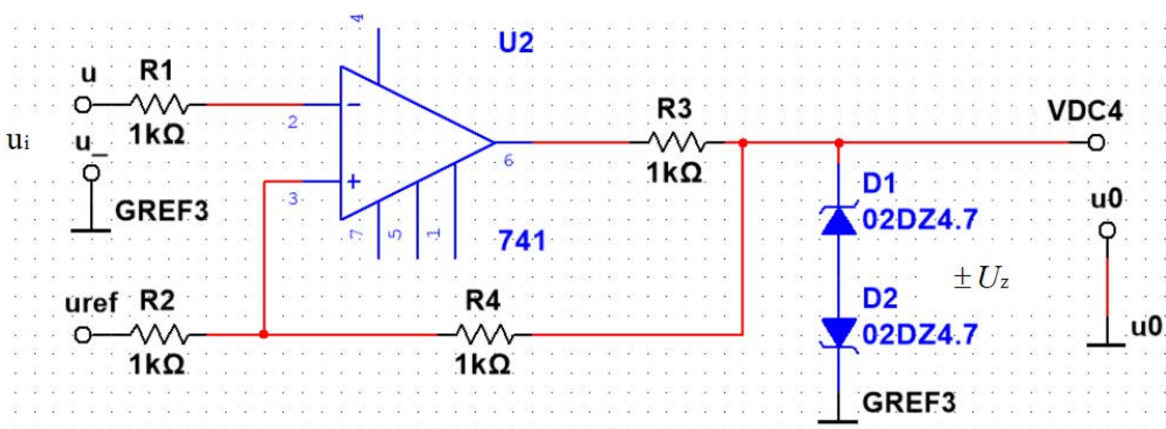

Fig. 3 Schematic diagram of inverse hysteresis comparator

R_4 constitutes positive and negative feedback, when the output section is connected to the non-inverting input through a resistor then the circuit is an inverting circuit, and the other way around, it is a positive circuit.

2.1.3 Input Voltage and Reference Voltage

u_i is the input voltage, uref is the reference voltage, and the regulator voltage is the regulator makes the output voltage (set the regulator on voltage to 0). This hysteresis comparator is inverted hysteresis comparator is shown in Fig. 3.

2.2 Theoretical Analyses

The threshold circuit determines the switching point of the circuit and can control the size of the hysteresis region. And the threshold circuit and the transfer characteristic curve are related to the input signal, and the input signal from low to high level corresponds to a threshold circuit and a characteristic curve, and from high to low level also has similar characteristics. So the hysteresis voltage comparator has two threshold voltages and two transmission characteristic curves. This leads to a two-part derivation [5].

2.2.1 Threshold Circuit

From the schematic diagram, the corresponding equations of the threshold circuit can be deduced [6]. Assuming that the input voltage is very small, so that the positive voltage of the operational amplifier is greater than the negative voltage, from the characteristics of the comparator can be seen, the output signal is high. At this time in the state of false break so the inverse phase voltage is 0, then $u_- = u_i$. And because of the false break, the current at the in-phase end of the comparator is 0, R2 is connected in series with R4, by the superposition theorem u_+.

$$u_+ = \frac{R_4 U_{REF}}{R_4 + R_2} + \frac{R_2 U_Z}{R_4 + R_2} \tag{1}$$

Let $u_+ = u_-$,Get:

$$u_i = U_H = \frac{R_1 U_{REF}}{R_4 + R_2} + \frac{R_2 U_Z}{R_4 + R_2} \tag{2}$$

If the input voltage is large enough which makes the positive stage voltage of the operational amplifier lower than the negative voltage, then the output voltage can be gotten as a low level -UZ, because of the false-break state inverse-phase voltage is 0,Then u- = u+ ,and the in-phase voltage is 0,can get,

$$u_i = U_L = \frac{R_4 U_{REF}}{R_4 + R_2} - \frac{R_2 U_Z}{R_4 + R_2} \qquad (3)$$

2.2.2 Transmission Characteristic Curve

From the above equation solving process, the transmission characteristic curve of the hysteresis comparator can be shown in Fig. 4,let $U_{TH}>0$,$U_{TL}<0$,

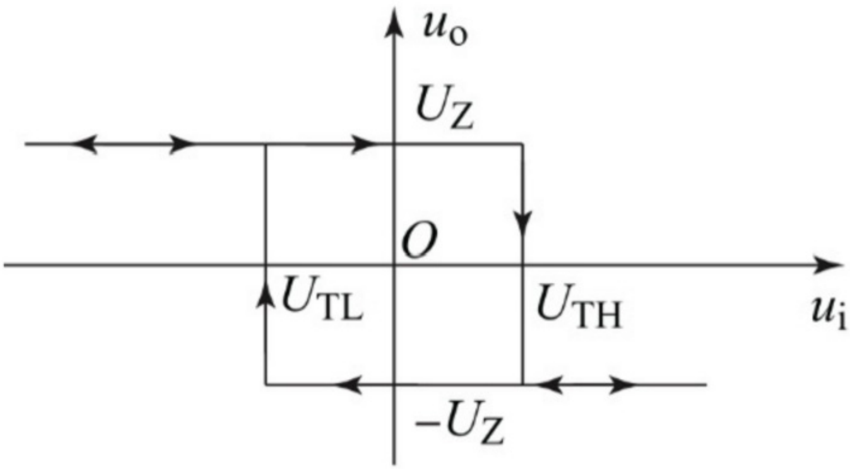

Fig. 4 Inverted hysteresis comparator circuit transmission curve graph

2.3 Design & Simulation

A simple hysteresis comparator can be designed from the schematic diagram as shown in Fig. 5

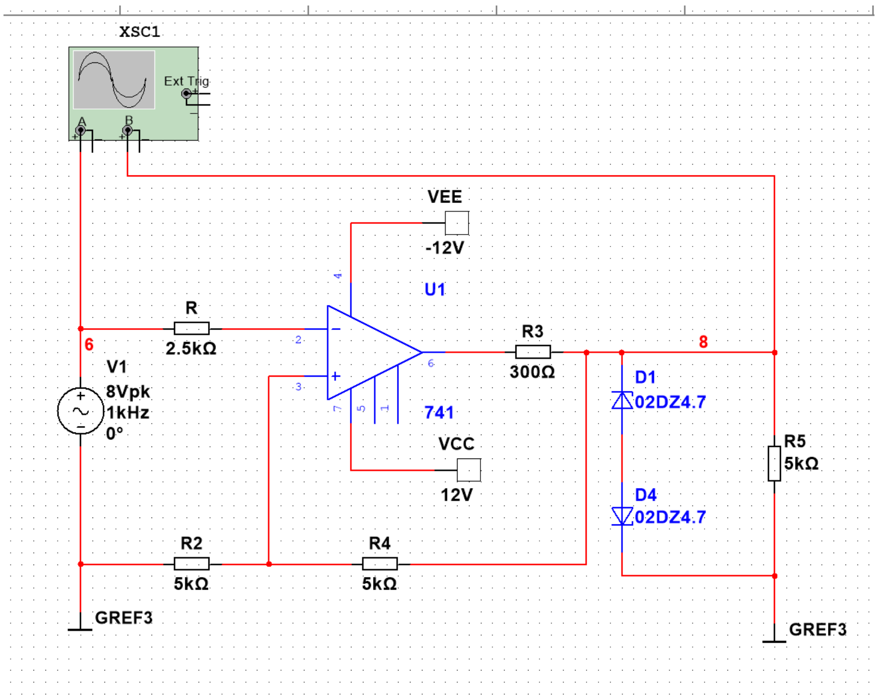

Fig. 5 Inverted hysteresis comparator

From the figure, the voltage of the voltage regulator $\pm U_Z$ =4.7V,conduction voltage U_D =1.3v, U_{REF}

=0V,then the output voltage can be calculated $U_0 = \pm(U_Z + U_D) = \pm 6V$

From the above formula, it is inferred that, U_{TH}=3V, U_{TL}=-3V.

Using DC Sweep Analysis to simulate the circuit, a threshold circuit for the hysteresis comparator and the results of the transmission characteristic curve are shown in Fig. 6.

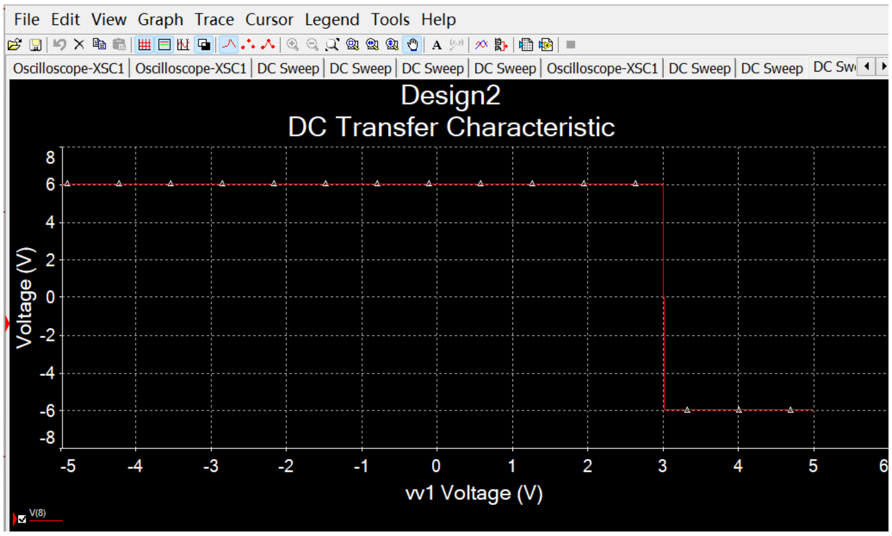

Fig. 6 Input signal from low to high circuit DC scanning results

It can be known that when the input signal is very small the output voltage is 6v high and the threshold voltage is 3v, when the input voltage is greater than 3v the output voltage becomes -6v.When the input voltage is greater than 3v, the output voltage becomes -6v.

Set the input signal frequency of 1khz, the peak value of 8v, and connected to the circuit and oscilloscope, switch to the B / A display mode can be gotten waveform as Fig. 7.

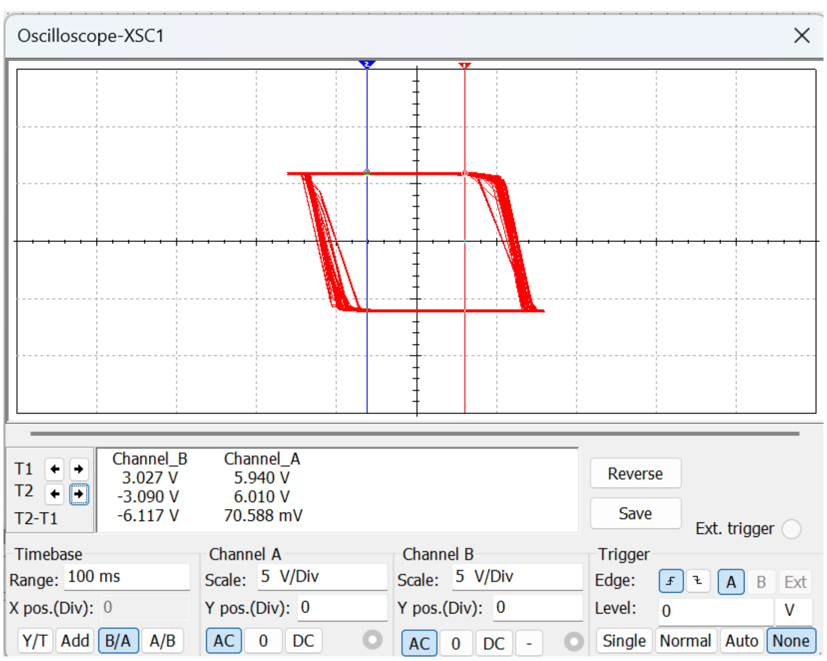

Fig. 7 Transmission characteristic curve of hysteresis voltage comparator

The results are consistent with the values and waveforms obtained from previous theoretical analyses.

Switched the display to Y/B mode, the output signal and input signal waveforms can be got, the characteristics of the hysteresis comparator can be clearly known, and the specific diagram is shown in Fig. 8.

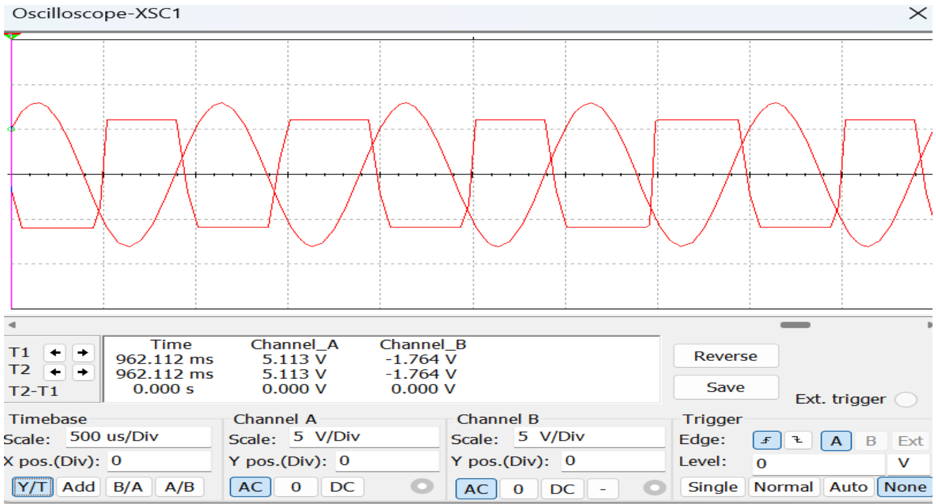

Fig. 8 Hysteresis voltage comparator input signal and output signal waveforms

3. Integrator

3. Design of the integrator

Function: Integrators are used in filters and signal conditioning circuits and are an important analog signal processor. It is usually used as an amplifier circuit with an integrated op-amp, which is widely used because of its ease of realization.

Design Idea: A simple integrator can be implemented by using an operational amplifier as an amplifier circuit and a capacitor and resistor as a feedback network [8].

3.1 Working principle and basic structure

The integrator consists of an operational amplifier, resistor and feedback capacitor.

The input signal is put in by the inverting input and the output section is fed back to the inverting input through a capacitor, by using the capacitor as a feedback capacitor. The schematic diagram is shown in Fig. 9 [9].

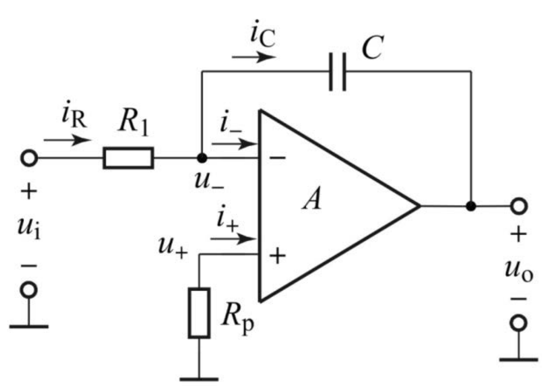

Fig. 9 Schematic diagram of integral circuit

3.2 Theoretical Analyses

$u_c = \frac{1}{C}\int i_c dt$ It can be gotten from the virtual short and the virtual break: $i_R = i_C = \frac{u_i}{R_i}$

It can be obtained from the capacitance: .

The output voltage can be calculated from the above formula:

$$u_o = -u_c = -\frac{1}{C}\int i_c dt = -\frac{1}{R_1 C}\int u_i dt \quad (4)$$

It is known that the output signal is related to the input signal [10].

3.2.1 Sine Wave Input:

Let a sinusoidal waveform be input with amplitude A and frequency f,then the input signal is $u_i = A\sin(\omega t) = A\sin(2\pi ft)$

,the output expression will be

$$u_o(t) = \frac{A}{2\pi f R_1 C}\cos(2\pi ft) \tag{5}$$

This expression proves that the output signal is a cosine signal after a sinusoidal input.

3.2.2 Square Wave Inputs

When square wave input is provided, the voltage value is stabilized and constant for a certain period of time is $u_i = U$, in another period of time the value of the voltage is $u_i = -U$.

The output voltage is expressed in the following formula

$$u_o = -\frac{1}{R_1 C}\int_{t_1}^{t_2} u_i dt + u_c(t_1) = -\frac{u_i(t_2 - t_1)}{R_1 C} + u_c(t) \tag{6}$$

The initial moment voltage is $u_c\ (0) = 0$

In $0 \sim t_1$, $u_o = -\frac{Ut}{R_1 C}$

In $t_1 \sim t_3$, $u_0 = \frac{2Ut}{R_1 C} - \frac{Ut}{R_1 C} = \frac{Ut}{R_1 C}$

In $t_3 \sim t_5$ $u_0 = -\frac{Ut}{R_1 C}$,

....

So when square wave is input, the signal is stabilized and the output is a triangle wave.

3.2.3 Triangle Wave Input

If the input signal is a triangular wave, the input voltage is a function of time $u_i = At + B$,and the output signal equation is

$$= -\frac{1}{R_1 C}\int (At + B)dt = -\frac{1}{R_1 C}(\frac{A}{2}t^2 + Bt) \tag{7}$$

It is known that the output voltage is a quadratic function [11,12].

3.3 Design & Simulation

According to the schematic design is shown in Figure 10.

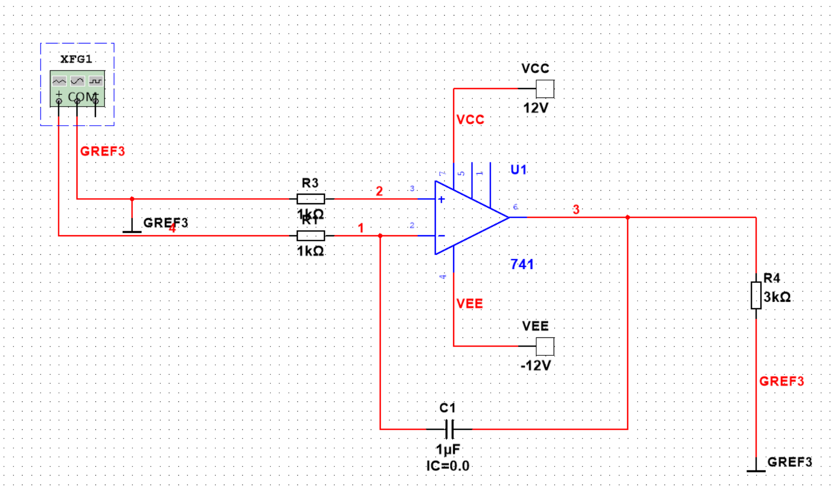

Fig. 10 Integrator

3.3.1 Sine Signal Input

Set the frequency to 1KHZ, the peak value is 100mV, the bias voltage is 0V, and the expression can be calculated from the formula

$$u_o(t) = \frac{A}{2\pi f R_1 C_1}\cos(2\pi ft) = \frac{0.1}{1\times10^3 \times 1\times 2\pi \times 1\times 10^3}\cos(\omega t) = 0.0159\cos(\omega t) \tag{8}$$

The waveform obtained by simulation is shown in Fig. 11

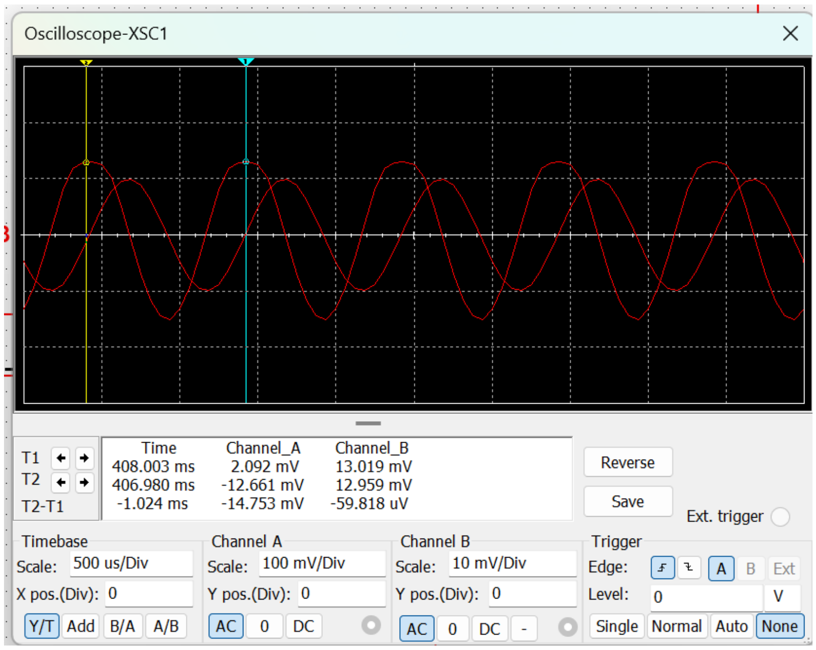

Fig. 11 Oscilloscope waveform at sine wave input

The output signal waveform can be got as a cosine waveform, and the signal amplitude is slightly deviated from the estimation result.

3.3.1 Triangle Wave Signal Input

The power source is set to a frequency of 1KHZ, a duty cycle of 50%, and an amplitude of 1 V, with a bias voltage of 0 V. The resulting graph is given in Fig. 12.

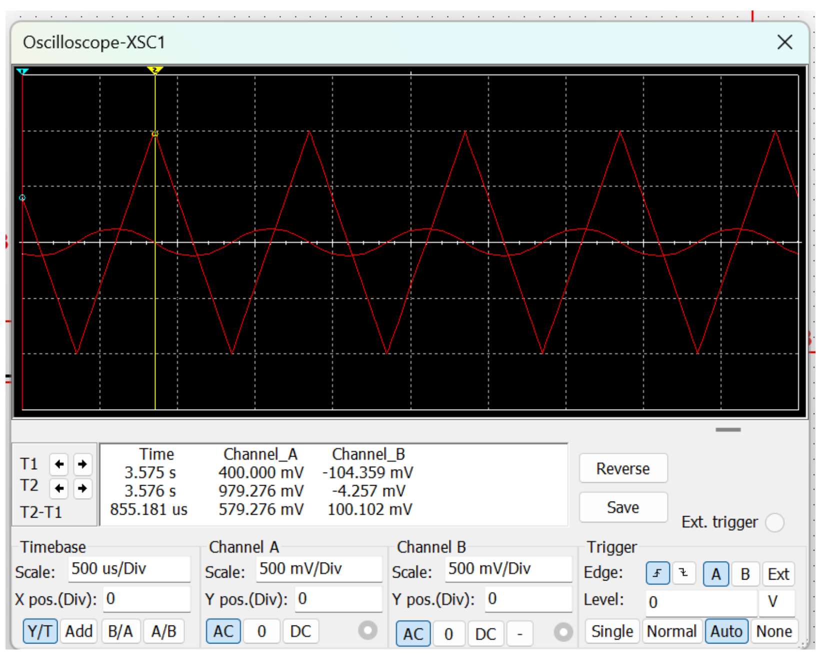

Fig. 12 Input and output signal waveforms at triangle wave input

Generally consistent with theoretical analysis.

3.3.2 Square Wave Inputs

The square wave signal is a DC bias voltage, and changes in the components in the circuit will have an effect on the output results. The signal bias voltage is 0, set the frequency of the signal source to 1KHZ, the amplitude is 1v, and other things are not changed. The output voltage peak value of -0.5V can be calculated by the formula, and the output and input waveforms are shown in Fig. 13.

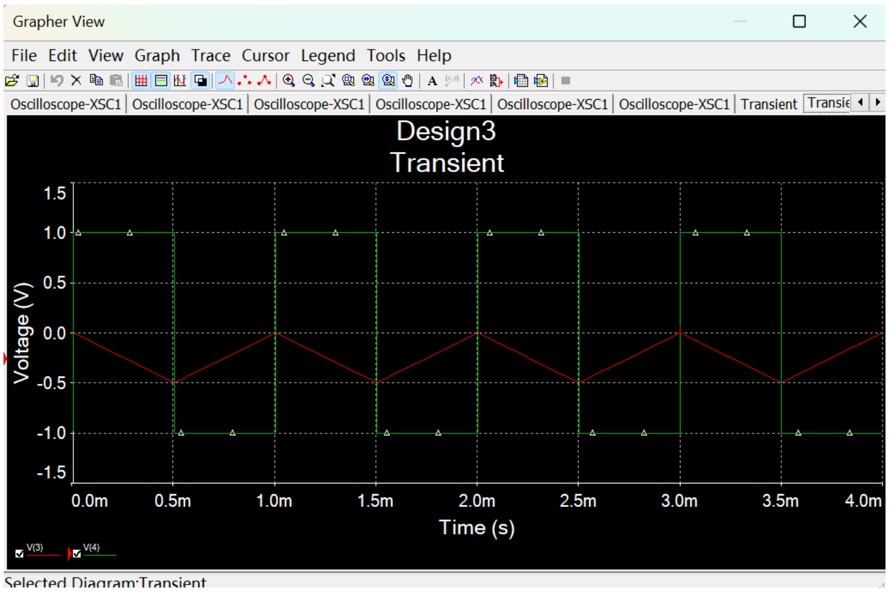

Fig. 13 Transient analysis results at R1=1KΩ

The output signal was found to be a triangular waveform with a peak value of 0.5, which is the same as the theoretical analysis.

Changing the value of R1 to 500Ω

The resultant graph is shown in Fig. 14.

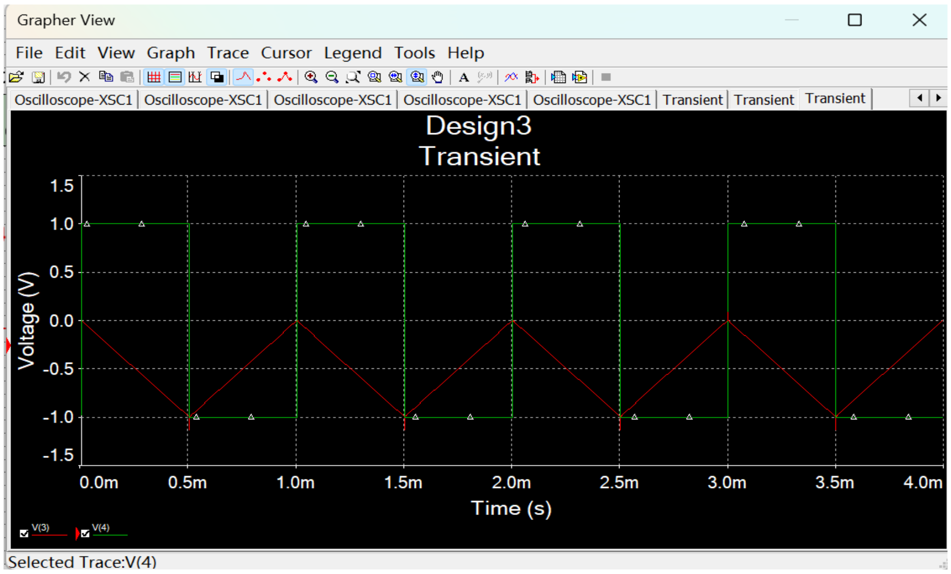

Fig. 14 $R_1 = 500\Omega$ Transient analysis results at time

It can be shown that the change in resistance will have an effect on the output results.

Signal offset is not 0

Different offsets of the input signal produce output signals.

Let the signal source data: frequency is 1KHZ, amplitude is 100mV, DC offset is 100mV. time range is $0 \sim 0.7$.

The results are shown in Fig.15.

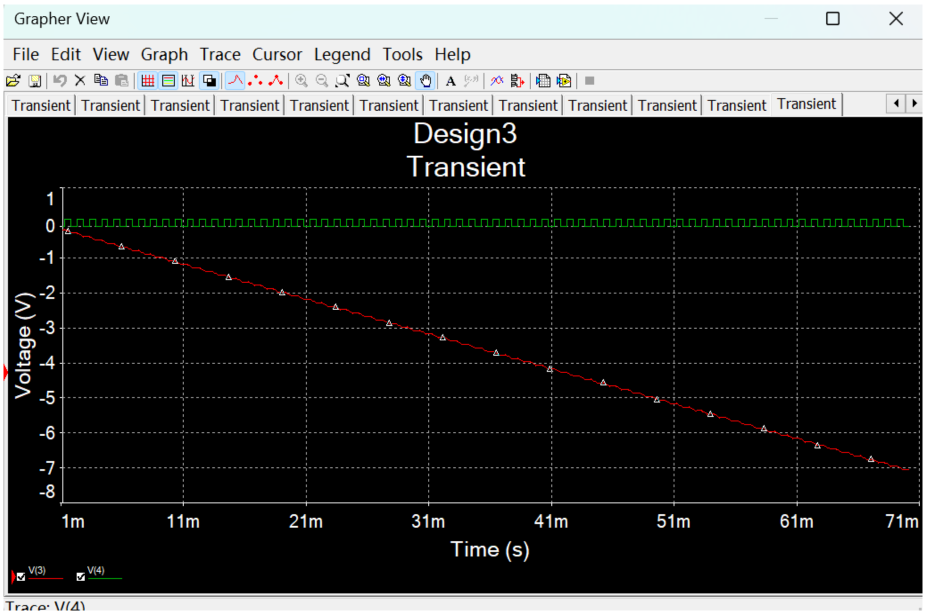

Fig. 15 Waveform of output signal

When the input signal is high, the capacitor is charged, and when it is low, the capacitor cannot be discharged, so the capacitor voltage keeps increasing, and the maximum value can reach the voltage of the power source.

Influence of initial value of capacitance

The output signal waveforms are different for different initial values of capacitance. Changing the initial value of capacitance to 0.1. by comparing the image with the previous initial value of 0, the resultant graphs are shown in Fig. 16, 17.

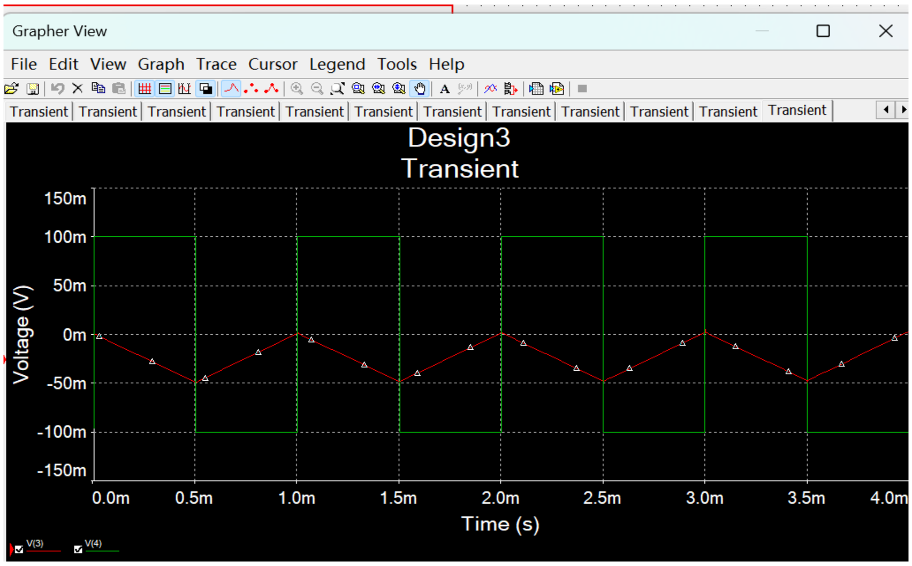

Fig. 16 Output signal waveform when the initial value of capacitor is 0V

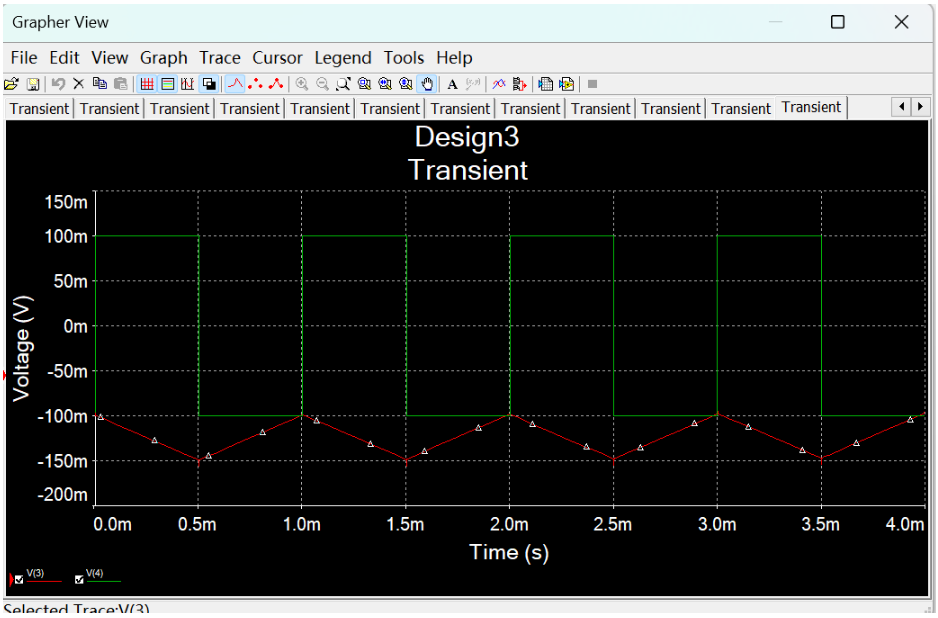

Fig. 17 Output signal waveform at a capacitance value of 0.1V

A significant change in the output waveform can be observed.

4.Summary

In this paper, the integrator and comparator are designed by means of operational amplifiers and feedback circuits, and the characteristics of the integrator and comparator are tested by using multisim simulation. The results of the experiment proved that this kind of design method is able to carry out high-precision signal processing to meet the needs of the majority of cases, and can fulfill the needs of daily life well, but there are still some slight shortcomings, especially in the design and power consumption, and will be improved in these aspects in the future.

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