Experiment 6: Integrated Operational Amplifier(1)

——Specifications Testing

and Basic Applications

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Objective

1. To know the main characteristics of integrated operational amplifier (Op-Amp).
2. To learn testing method of Op-Amp's performance specifications.
3. To study Op-Amp applications in analog operations.
4. To learn to measure the voltage transmission characteristic of hysteretic comparator by oscilloscope.

Principle

Basic knowledge

(1) An operational amplifier is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. It produces an output voltage that is typically millions of times larger than the voltage difference between its input terminals.

(2) Typically, its very large gain is controlled by negative feedback, which largely determines the magnitude of its output ("closed-loop") voltage gain in amplifier applications, or the transfer function required (in analog computers).

(3) Without negative feedback, and perhaps with positive feedback for hysteresis, it essentially acts as a comparator. High input impedance at the input terminals (ideally infinite) and low output impedance at the output terminal(s) (ideally zero) are important typical characteristics.

1. Main performance specifications

Open-loop gain

$$A_{od} = \frac{U_o}{U_+ - U_-}$$

Input base current

$$I_B = \frac{I_{B+} + I_{B-}}{2}$$

Input offset current

$$I_{os} = \left| I_{B+} - I_{B-} \right|$$

Input offset voltage

$$U_{IO} = -\frac{U_O \big|_{u_I = 0}}{A_{od}}$$

Unit gain bandwidth

Slew rate (SR) $$SR = \left| du_o / dt \right|_{\max}$$

Power supply rejection ratio (PSRR) $$PSRR = 20\lg \frac{\Delta U_{pf}}{\Delta U_{of}}$$

Common-mode rejection ratio (CMRR) $$CMRR = 20\lg \frac{A_d}{A_c} (dB)$$

2. Basic operational circuits

In an operational circuit, the output is one of the input's operational results. OA works at linear district, and feedback is used to realize mathematic operation.

For example,

Summing operation: UO=A(U1+U2)

Integral operation: $$u_0 = -\frac{1}{RC}\int_{t_1}^{t_2} u_i dt + u_o(t_1)$$

3. Hysteretic comparator

For hysteretic comparator, OA works at saturation, whose output is whether +Ucc or –Ucc. Positive feedback is adopted

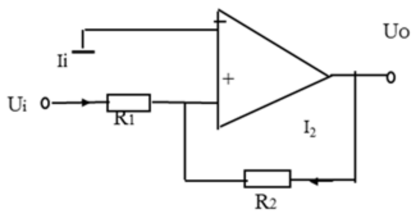


图 2-14-1

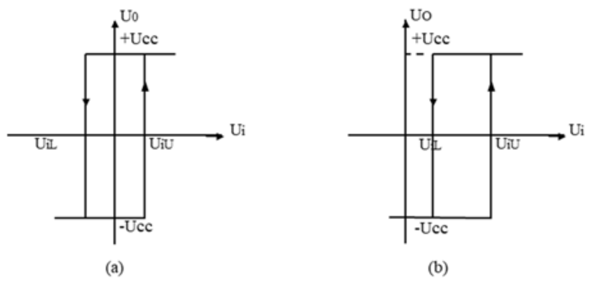


图2-14-2

Experiment circuits and task

1.Op-Amp specifications testing

(1) Offset voltage

According to your simplified circuit, RF1=100KΩ, make RG=100 Ω or 1K Ω, measure output U_O to get offset voltage UIO.

the simplified circuit is drawn as diagram 1.

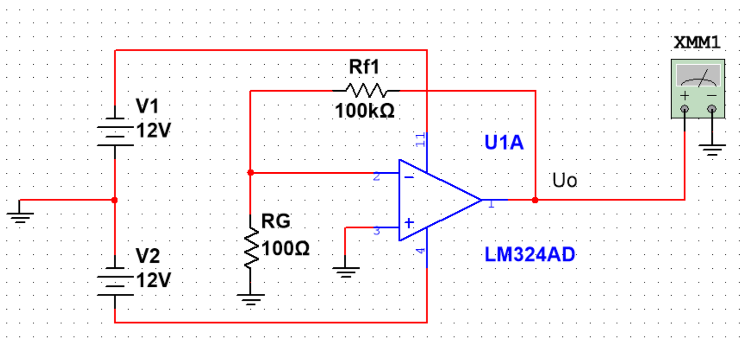


Diagram 1

(2) Slew rate

According to your simplified circuit. Set input signal **1KHz square wave**, and adjust input amplitude to make output **peak to peak value 4V**. Observe output up-edge and measure slew rate.

The simplified circuit is drawn as diagram 2.

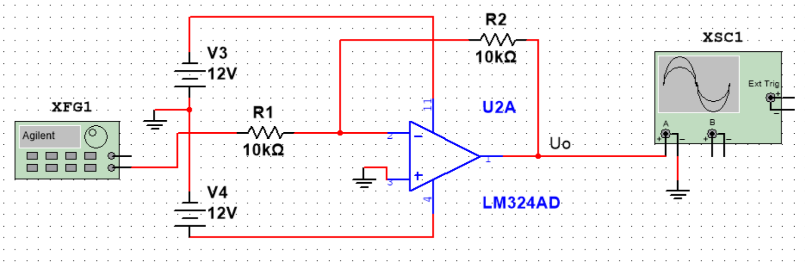


Diagram 2

2. Linear application circuits

(1). Inverting summing circuit

Build the circuit. According to the table, measure output values. I draw the circuit as diagram3.

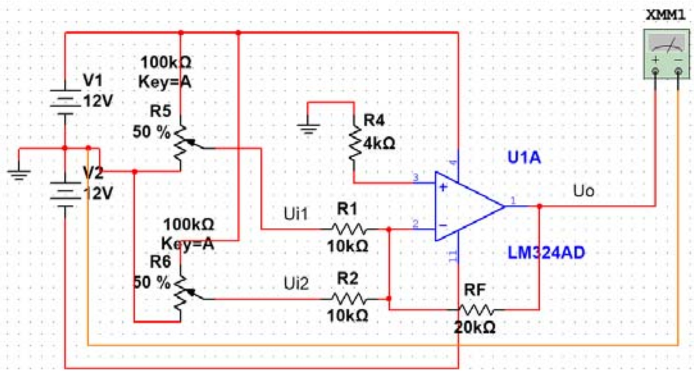


Diagram 3

In this experiment, R4=R1//R2//RF, so R4=4kΩ.

After calculating, $U_0 = -2(U_{i_1} + U_{i_2})$.

(2). Differential amplifier circuit

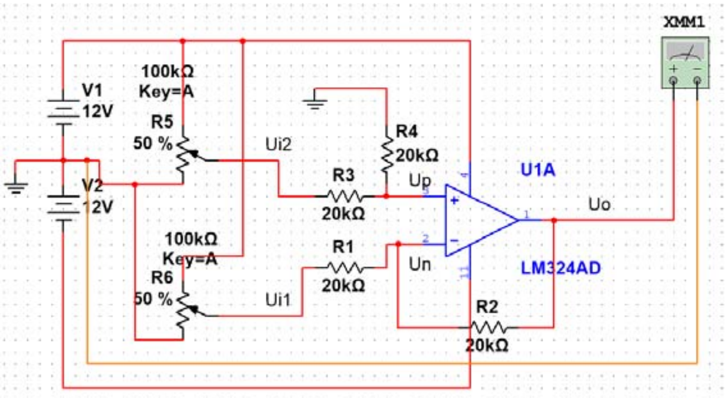


Diagram 4

Build the circuit based on the parameters you designed, and measure output values.

I choose R1=R2=R3=R4=20kΩ. The measure circuit is diagram4.

The relationship of Ui and Uo is calculated as follows:

According to Kirchhoff's law:

$$\frac{U_0-U_N}{R_2}=\frac{U_N-U_{i1}}{R_1}\quad(1)\qquad\frac{U_{i2}-U_P}{R_3}=\frac{U_P}{R_4}\quad(2)$$

Because the amplifier has negative feedback: $U_N=U_P$ (3)

Based on equation (1)(2)(3),

$$Uo=\frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)U_{i2}-\frac{R_2}{R_1}U_{i1}\quad(4)$$

So if I choose R1=R2=R3=R4=20kΩ, $Uo=U_{i2}-U_{i1}$.

(3). Testing amplifier

Build the circuit. Measure its voltage gain.

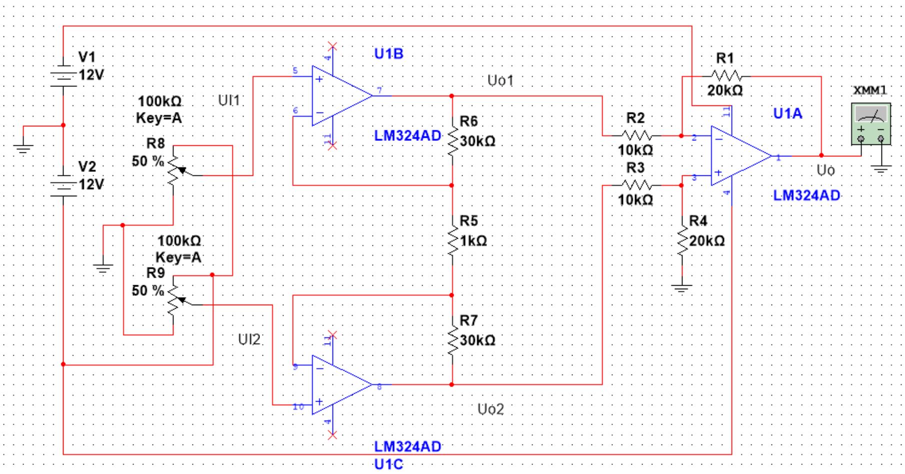


Diagram 5

The circuit is drawn as diagram 5.

Because the input resistance of amplifier is very high, so R5, R6 and R7 can be viewd as series. So relationship of Ui and Uo is:

$$U_{02}-U_{01}=\frac{R_1+R_2+R_3}{R_2}\cdot(U_{i2}-U_{i1})$$

$$Uo=\frac{R_4}{R_3+R_4}\left(1+\frac{R_2}{R_1}\right)U_{o2}-\frac{R_2}{R_1}U_{o1}$$

After calculation, I know $Uo=122(U_{i2}-U_{i1})$.

(4). Integrator

① Build the circuit.

② Ui = -1V, C=47uF, switch on and off K, and observe how Uo changes with time. Measure saturation output voltage and integral time.

③ C = 0.2uF. Switch off K, and set input signal sine wave Ui = 1v, f = 100Hz. Observe amplitudes and phase shift between Uo and Ui on oscilloscope.

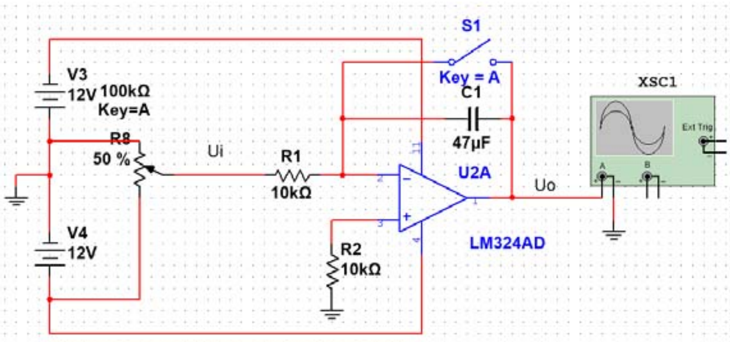


Diagram 6

According to Kirchhoff's law: $\frac{U_1}{R_1} = -C\frac{dU_0}{dt}$

So $U_0 = -\frac{1}{R_1 C}\int_{t_1}^{t_2} U_i\, dt + U_0(t_1)$. And $|U_0|$ max is Uom. After calculating, the integral time is 5.64s.

If Ui is Ac, $\dot{U}_0 = \frac{-jwC}{R_1}\dot{U}_i$ so the shift phase shift between Uo and Ui is -90°.

3. Non-linear application circuit

(1) Build the hysteretic comparator circuit. I draw the circuit as diagram 7.

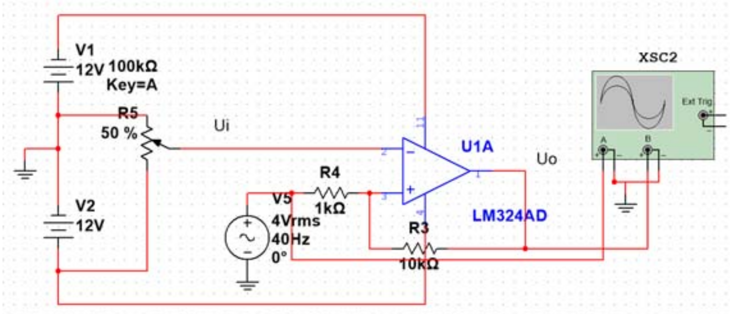


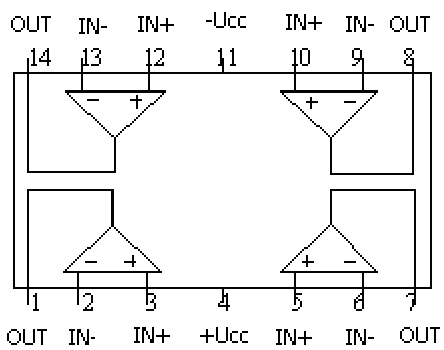
Diagram 7

(2) Measure hysteretic characteristic on oscilloscope. Set Ui 40Hz sine wave. Change UR to see how the wave changes with it.

(3) Draw voltage transmission waves on square paper when UR=0.5V and UR=-0.5V.

Instruments

Operational amplifier LM324, Oscilloscope, DC power supply, function generator, digital multimeter



LM324 Pin-out diagram

Cautions

1. Connection way of positive/negative power supply.
2. Make sure to connect the proper positions of positive and negative power of the operational

amplifier.

3. Don't misconnect the inputs and output of operational amplifier.
4. Pin-out diagram of LM324.
5. Switch off the power before changing circuit.

Data collation and analysis

1.Op-Amp specifications testing

(1) Offset voltage

$R_G(\Omega)$	100	1000
Closed loop gain Au	1000	100
Uo(V)	0.682	0.0725
offset voltage U_{IO}=Uo/Au (mV)	0.682	0.725

(2) Slew rate

Peak-to-peak value ΔU(V)	Up-edge time t(μs)	Up-edge speed S=ΔU/t (10^6V/s)
4.02	13.20	0.3045

The waveform is drawn as figure 1:

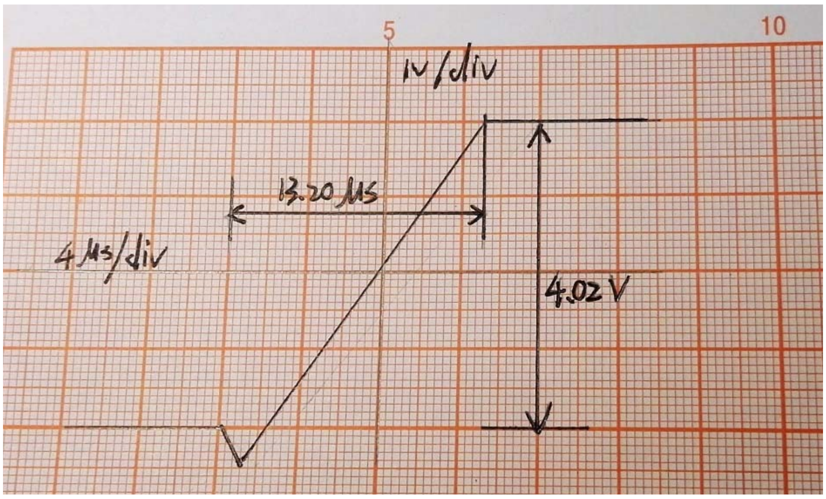


Figure 1 slew rate measurement waveform

Y:1V/div X:4μs/div Vp-p=4.02V

2. Linear application circuits

(1). Inverting summing circuit

U_{i1} (V)	0.5	-0.805	4.074
U_{i2} (V)	0.5	0.304	3.998
U_O (V)	-2.004	1.020	-11.376

Uo in theory Uot(V)	-2.000	1.002	
Relative error $\eta = \frac{\lvert U_o - U_{ot}\rvert}{U_{ot}} \times 100\%$	0.20%	1.80%	

(2). Differential amplifier circuit

U_{i1}(V)	0.2025	2.027	2.200
U_{i2}(v)	-0.2021	2.014	1.806
Uo(V)	-0.4092	-0.026	-0.451
Uo in theory Uot(V)	-0.4046	-0.013	-0.394
Relative error $\eta = \frac{\lvert U_o - U_{ot}\rvert}{U_{ot}} \times 100\%$	1.14%	100%	14.47%

The data Uo1 on my recording paper is -4.092, I guess that I misplaced digits. When I do the experiment, I always want to finish every small experiment as quickly as possible, in order to finish as much experiments as possible. But because of my eagerness for success, I often make mistakes, as the result, the experiment I have finished may have wrong data. Next time, I should focus on what I am doing, make sure that do every little experiment as serious as possible.

And for the second column, the relative error is very large. Based on datasheet of LM324, it has offset voltage, so if Uo is small enough, the offset voltage will cause more and more error. That's maybe why the relative error of this set of data is so large.

(3). Testing amplifier

I have some problems when do this experiment, the data is wrong. I record it as follows:

U21(V)	U22(V)	UI(V)	Uo(V)	Au=Uo/UI
3.023	3.214	0.191	10.814	56.62

From this experiment, I realize that the more complex the circuit is, the more likely to make mistakes. So when I lap circuit from now on, I should separate the big circuit into small parts, and test them. Then sum them up, to rise up success rate.

(4). Integrator

I haven't finish this, so I make simulation.

Ui=-0.995mV, and simulation result is as figure 2, simulation circuit is figure 3.

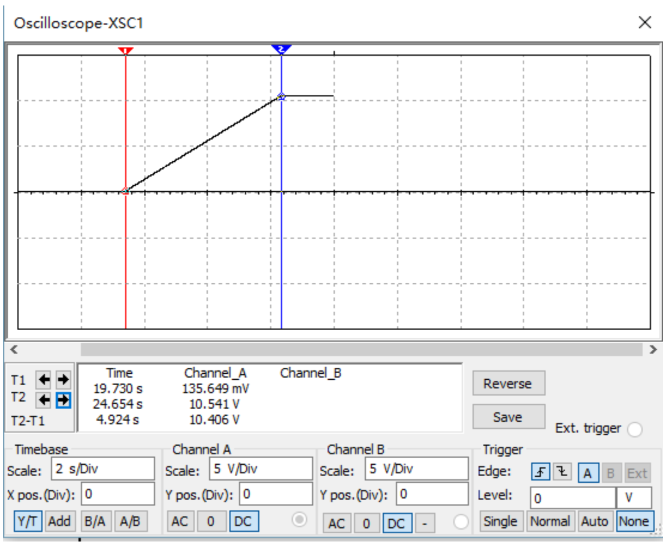


Figure2 Simulation result of (1)

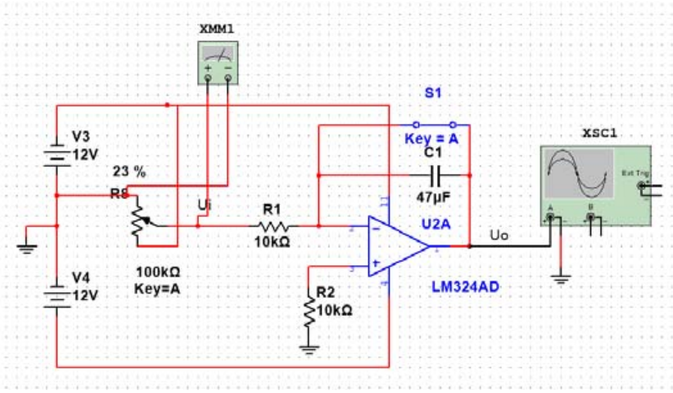


Figure 3 Simulation circuit of (1)

From figure 2, integral time is 4.924s.

（2）C=0.2uF, Ui=1V 100Hz.

Simulation result is as figure 4.

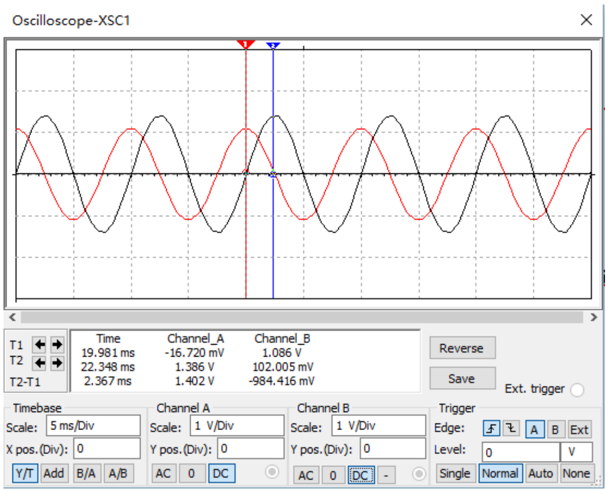


Figure 4 Simulation result of (2)

From figure 4, the phase shift is nearly 90°.

3. Non-linear application circuit

I draw the waveform as follows.

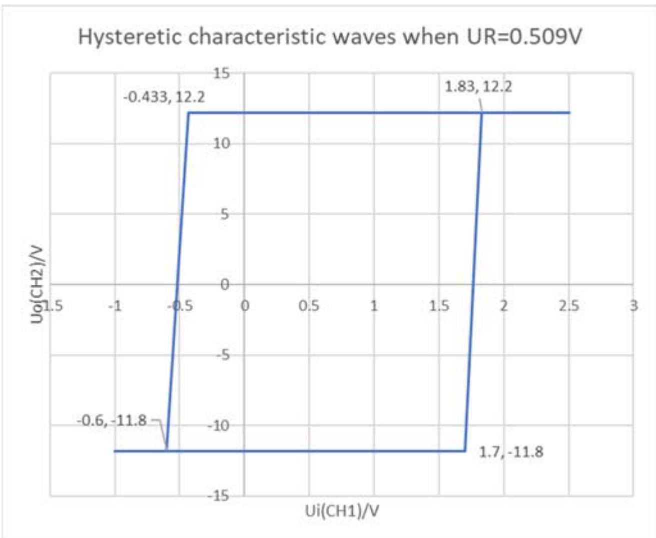


Figure 5 Hysteretic characteristic waves when UR=0.509V

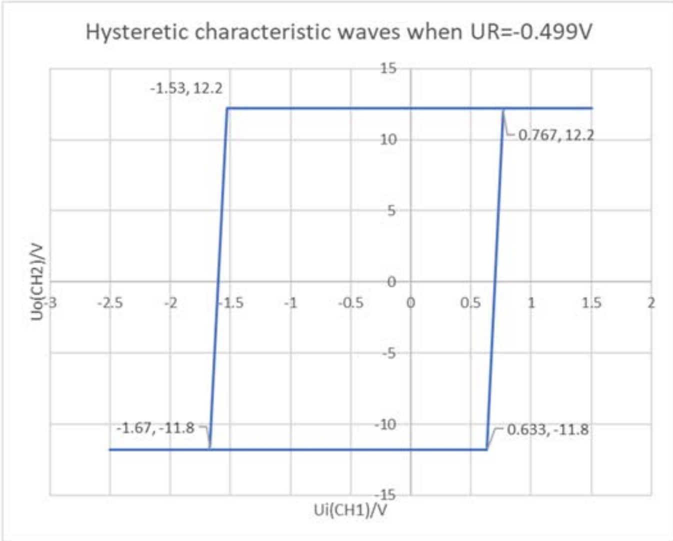


Figure 6　Hysteretic characteristic waves when UR=-0.499V

Change UR, the waveform will change position, and the change of center point is equal to UR. If UR is greater than zero, waveform will change to right; and id UR is smaller than zero, waveform will change to left.

Summary and problem discussion

The amount of this experiment is very large, so preview is extremely important. Next time I should prepare more fully.