

A Method of Testing Integrated Operational Amplifier Gain Characteristics

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Abstract. When integrated operational amplifier (Op amp) is tested under open-loop, output voltage keeps swinging. Especially for high gain integrated Op amp, oscillation is stronger due to severe drift. This paper presents a method that using two aid amplifiers. The basic idea is testing the input signal and output signal of the integrated Op amp indirectly with two aid amplifiers to obtain the open-loop gain. The output signal is measured by aid amplifier 1(AD8055_1) which is a voltage follower in the circuit, and the input signal is tested by aid amplifier 2(AD8055_2) which can amplify input signal tenfold. The results show that this method overcomes the measurement errors caused by zero drift and errors generated in testing small signals. All signals are analyzed precisely by network analyzer (NA).

Keywords: operational amplifier; open-loop; aid amplifiers; voltage follower; zero drift

1. Introduction

Integrated Op amp, like other semiconductor devices, is a linear integrated circuit. Its performance is evaluated by some parameters such as open-loop gain, input and output resistors, CMRR, SNR, input offset voltage and current, and so on. In order to use the integrated Op amp properly, its main performance parameters must be clear. This paper provides a method to measure Op amp's open-loop voltage gain. The DC gain of integrated Op amp without external feedback is called open-loop gain. However, due to temperature variation, supply voltage fluctuations, and component aging, there exists zero drift that will change the operating point of amplified circuit. This variation will be progressively enlarged by the direct coupled amplified circuits, and will result in variation of the output signals. The output voltage deviates from the original point and sways up and down. Therefore, testing Op amp's open-loop gain is very hard [1].

For high gain Op amp, zero drift will be more serious, another inevitable problem is that input signal is small which increases the difficulty of testing. It is not accurate enough to assemble, debug and screen by multimeter and oscilloscope. In order to decrease zero drift and avoiding the measurement of small amount, a new method is proposed to test integrated Op amp's gain using two aid amplifiers. All tested data are analyzed by NA. The paper is organized as follows. Section II is dedicated to present the disadvantage of ordinary test, and introduce the proposed test method principle and the working principle of NA. Then, in the section III, the test method is applied to an Op amp (AD318), and come to the results. The matters needed to consider are also listed. And Conclusions are discussed in Section IV [2].

2. Test Principle

As the gain of modern integrated Op amp has been improved up to 105~108 and the magnitude of input current has been decreased to Pico Ampere (PA). The determination of DC parameters is related to the testing of very large and very small amount. The open-loop gain is very difficult to test directly. So, closed-loop testing method is used [3]. However, there still exist deviations with using close-loop structure separately. It

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can be found in following A and B. Close-loop structure and amplifiers combined to build test circuit to test the open-loop gain of Integrated Op amp is a good method as mentioned in C.

2.1. DC, AC closed at the same time

In fig.1, after the low-frequency AC signal is inputted, the open-loop gain of the Op amp can be obtained as long as U_o and U_i are tested. It is:

$$Ax = \frac{U_o}{U_i} \quad (1)$$

However, there are lots of errors in this result, and this test method is difficult to achieve. Because U_i is so small that it can not be measured accurately, and the phase difference between feedback signal and input signal will lead the distortion of the U_i waveform. For high gain Op amp, its impact is worse.

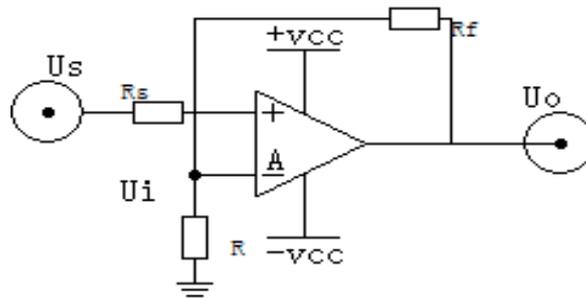


Figure 1. Test open-loop gain under close-loop

2.2. DC closed and AC opened

In fig.1, if integrated Op amp's frequency is low or intermediate, R_s can be replaced by capacitor C , and grounded. The use of C is to make the AC feedback signal zero. So, DC is close-loop and AC is open-loop in this circuit. The open-loop gain of the Op amp is:

$$Ax = \frac{U_o}{U_i} \quad (2)$$

If the test frequency is f , in order to achieve the requirements of the AC open-loop, f must satisfy $2\pi f R_f C < Ax$. In the formula, f should be less than -3db bandwidth of the op-amp at least. This method is limited by the frequency. For high frequency testing, this method is not available [4].

2.3. Testing with aid amplifiers

As the factors discussed above, the new test method is presented. The corresponding circuit and PCB board are shown in fig.2. With this method, the accurate open-loop gain of integrated Op amp can be obtained. In fig.2, OP-TEST is a tested integrated Op amp, its output voltage, input voltage and open-loop gain are marked as V_{out} , V_{in} , and A_x . So, there is:

$$Ax = \frac{V_{out}}{V_{in}} \quad (3)$$

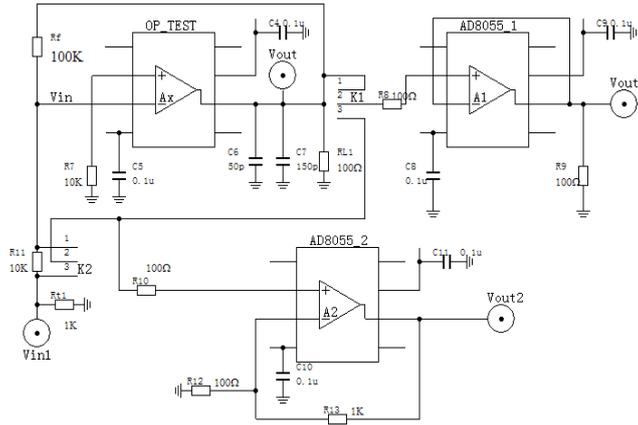


Figure 2. Testing circuit with aid amplifiers

The input signal V_{in1} is provided by the network analyzer. And the network analyzer receives the output voltage of the two aid amplifiers. AD8055-1 is a voltage follower whose gain is marked as A_1 . The theoretical value of A_1 is 1. If point 1 and 2 are closed in switch1, then V_{out} can be expressed as:

$$V_{out} = \frac{V_{out1}}{A_1} \quad (4)$$

So, AD8055-1 as a voltage follower used to get V_{out} indirectly. AD8055_2 is an aid amplifier with a negative feedback. Its closed-loop gain is marked as A_2 . Its theoretical value is 10. If point 1 and 2 are closed in switch2, there is:

$$V_{in} = \frac{V_{out2}}{A_2} \quad (5)$$

V_{in} is magnified tenfold by AD8055_2. So testing of small amount is avoided. A_x can be expressed as:

$$A_x = \frac{A_2}{A_1} \times \frac{V_{out1}}{V_{out2}} \quad (6)$$

For integrated Op amp, V_{in} is very small and V_{out} is very large. If testing them directly, the results will have large deviations as mentioned in A. Now from formula (6), the obviously advantage is avoiding to test input and output signals (V_{out} and V_{in}) of Integrated Op amp directly. The more important benefit is that zero drift is decreased by AD8055-2 which has a negative feedback. Both A_1 and A_2 are only related to aid amplifiers' parameters. They can be got easily by the network analyzer. But V_{out1} and V_{out2} can not be got directly by network analyzer. For easily and conveniently, another method is adopted that formula can be rewrite as follow:

$$\frac{V_{out1}}{V_{out2}} = \frac{V_{out1}}{V_{in1}} \times \frac{V_{in1}}{V_{out2}} \quad (7)$$

If $H_1 = \frac{V_{out1}}{V_{in1}}$ and $H_2 = \frac{V_{out2}}{V_{in1}}$, there is:

$$\frac{V_{out1}}{V_{out2}} = \frac{H_1}{H_2} \quad (8)$$

As A1 and A2, H1 and H2 can be got easily by the network analyzer. The difference is that H1 is not only related to aid amplifiers but also to Integrated Op amp, measurement will be complicated. By formula (6) and (8), the open-loop gain of Integrated Op amp is:

$$Ax = \frac{A_2}{A_1} \times \frac{H_1}{H_2} \tag{9}$$

The measurement method of how to get the four parameters will be detailed in section III. There, we will give four simplified schematics to do the test.

2.4. The working principle of NA

The main instrument used in testing process is E5071C NA which is shown in fig.3 (a). It includes the signal source, S parameter test system (the signal separation circuit), amplitude, phase receiver and display parts. fig.3 (b) shows the overall system block diagram of NA.

Excitation signal is generated by signal source. The input signal R, reflected signal A and transmission signal B of DUT are separated by the signal separation circuit. These signals are converted to fix IF signal with sampling frequency conversion technologies. Then the amplitude and phase relationship can be obtained. In the frequency conversion process, the system phase locking technique is used to ensure that the amplitude and phase information of the tested network are not lost. The first IF signal which contains the amplitude and phase information of the tested network is transferred into the second IF signal by IF processing circuit, and then converted to digital signals by A/D converter. The amplitude and phase information of the DUT are extracted from the digital signal by the internal computer and DSP. The S-parameters of DUT are obtained through the ratio. Finally, the test results are displayed graphically on the LCD screen [5].

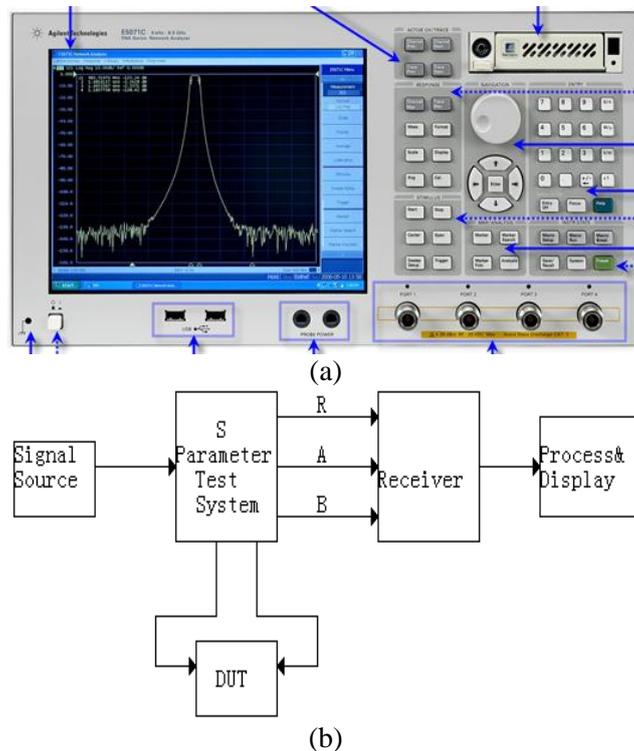


Figure 3. E5071C NA (a) the demo testing IC use network analysis; (b) working principle schematic of NA

3. Test Process

The testing circuit's schematic and PCB board are shown in fig.2. Integrated Op amp (AD318) is placed at the OP-TEST. In this circuit, according to formula (9), H1, H10, A1 and A2 should be tested so as to calculate the open-loop gain of AD318. NA provides all input and receives all output. After analysis and processing of logarithmic, each measured parameter is displayed in graphically on the LCD screen. In this test

process, the frequency of signal source ranges from 1MHz to 10MHz, and the signal power is set at 0dB. Measurement steps are as follows:

3.1. Test A1

In fig.2, AD8055-1 is a voltage follower in the circuit. The theoretical A1 is 1. With variation of temperature and frequency, and other factors, A1 will change slightly. In order to decrease errors, testing A1 is needed. Point 2 and 3 should be closed in both of switch K1 and K2. It will be convenient, if the principle schematic is simplified as fig.4 shown.

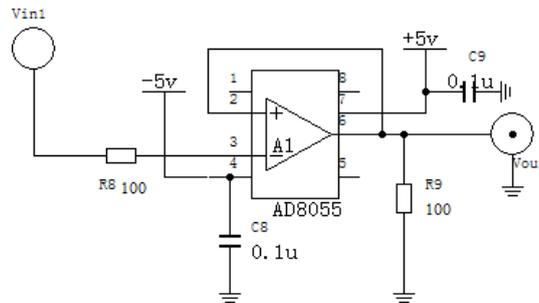


Figure 4. Simplified schematic of testing A1

3.2. Test H1

Input signal is amplified by AD318 and then amplified by AD8055_1, the gain is H1 that the gain of Vin1 to Vout1. Point 1 and 2 of switch K1 should be closed, K2 should be opened. As shown in following fig.5.

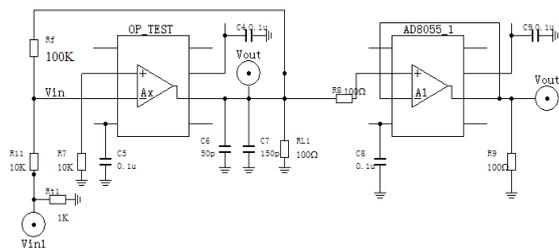


Figure 5. Simplified schematic of testing H1

3.3. Test A2

In fig.2, AD8055_2 is an aid amplifier with a negative feedback. The theoretical A2 is 10. But as A1, testing it is needed. Point 2 and 3 should be closed in K2. K1 is opened. As shown in fig.6.

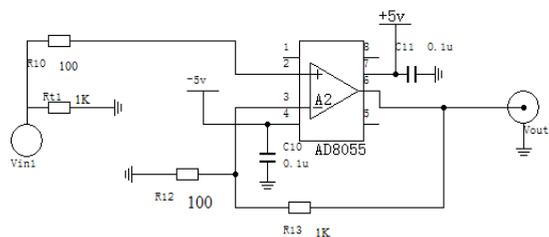


Figure 6. Simplified schematic of testing A2

3.4. Tset H2

Input signal Vin1 goes through R11, then it is amplified by AD8055_2, the output is Vout2. The gain of Vin1 to Vout2 is H2. Point 1 and 2 should be closed in K2. K1 is overpass. As shown in fig.7.

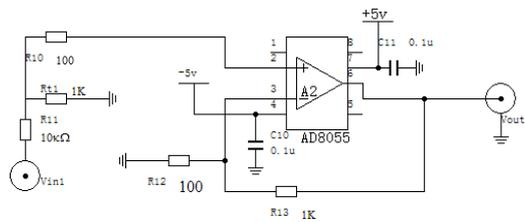


Figure 7. Simplified schematic of testing H2

3.5. Test results

All the parameters' amplitude and phase information are derived from the NA, then, the open-loop gain of AD318 can be calculated according to formula (9). NA has done processing logarithmic for the parameters. Amplitude-frequency and phase-frequency characteristics are respectively shown in fig.8. It can be found that the gain's amplitude decreases with the rising of frequency. This is consistent with the theory that gain's amplitude decreases with the rising of frequency because of the impact of parasitic capacitance. There is a few of differences between tested phase and its theoretical value. According to the analysis, the result is possibly caused by electromagnetic signals around.

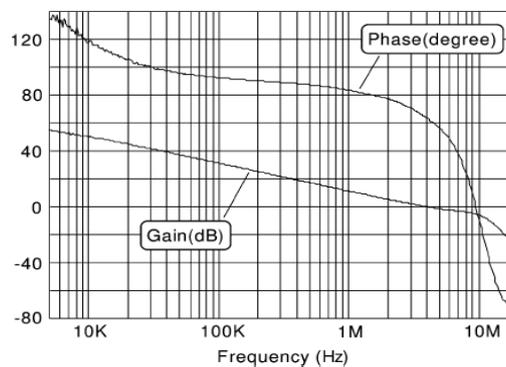


Figure 8. Test results: amplitude-frequency characteristics and phase-frequency characteristics

3.6. Measurement Notes

Firstly, before the test, the values of all supply power must be checked and set at normal range to ensure amplifiers not to be damaged and work in saturate region. Secondly, the tested integrated Op amp and aid amplifier should be powered separately. Thirdly, the input signal only can be added after the Integrated Op amp and aid amplifiers are working formally. Lastly, good circuit filter should be set to prevent electromagnetic interference and crosstalk in circuits.

4. Conclusion

A method of testing integrated Op amp open-loop gain characteristic based on aid amplifier has been proposed. In this proposed method, AD8055_1 as a voltage follower and AD8055_2 with a tenfold negative feedback, the disadvantage of zero drift and measurement of very small signal are overcome. Final data are obtained by the NA. And with accuracy instrument, the measurement errors caused by the instrument itself are reduced. This method can be used to test not only the open-loop gain characteristics, but also important parameters of the integrated Op amp, such as Input and output resistors, CMRR, SNR, input offset voltage and current, and so on.

5. Acknowledgment

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6. References

- [1] HU Saichun, QIU Biao, ZHOU Laixiu, "Index Test of the Integration Transports Puts Based on Multisim10", Journal of Hainan Normal University Vo1.23 No.1 Mar.2010, pp: 29.

- [2] Dux and nhui, "The Paraement of IC Wased Tested Method by Using Step-by-step Excitation, Step-by-step Sample", Journal of Test and Measurement Technology Vol.12 No.13 1998 Sum.25 pp: 324.
- [3] Karim Arabi and Bozena Kaminska, "Testing Analog and Mixed-Signal Integrated.
- [4] Ping Zhong, "Main Parameters of Auxiliary Amplifier for Testing Integrated Calculating Amplifier", JOURNAL OF GANNAN TEACHER'S COLLEGE No.6 Dec. 1999, pp: 66.
- [5] GU Xinhai, "Principle of Operation of Network Analyzer and Its Application to Electrical Measurements", Electronic Engineer Vo.l 34 No. 7 Jul 2008 pp: 715.