Proceedings of the 2nd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/19/20230541

Research on the stability of negative feedback circuit

Xinai Liu

SDU-ANU Joint Science College, Shandong University, Weihai, Shandong Province, China, 264200

202000700083@mail.sdu.edu.cn

Abstract. The negative feedback amplifier circuit generally plays a role in stabilizing the signal and improving its accuracy, and is widely used in production and life. Therefore, it is extremely important to discuss its stability. This paper analyzes the advantages and disadvantages of different methods for judging stability through literature analysis, case analysis and comparative analysis, and gives two solutions to improve the circuit stability in combination with the circuit oscillation problem that may occur in actual operation This paper draws a conclusion that the oscillation can be reduced from two aspects: changing the additional phase shift after compensating the capacitance hysteresis or reducing the feedback depth.

Keywords: negative feedback circuit, stability, circuit oscillation, performance analysis

1. Introduction

In the circuit, the change of the output signal in a certain direction is called the change source, and the change of the output signal after it returns to the input terminal is called the secondary change [1]. If the change source is opposite to the direction of the secondary change, it is defined as negative feedback. In the improvement of circuit performance, the application of negative feedback amplification circuit plays a very important role, such as reducing the distortion of the amplifier circuit, expanding the passband of the amplifier circuits, stabilizing circuit signal, and improving the accuracy of output signal[2]... Therefore, it is widely used in circuit design to solve important problems in industrial production and calculation effectively, with certain practical application value. At present, different people in the field have studied the stability of negative feedback amplifier circuits with the traditional Byrd diagram method, loop gain Nyquist diagram analysis method and amplitude and phase margin analysis method respectively, but they have not analyzed the limitations of each method. This paper will introduce three methods to analyze circuit stability by analyzing relevant literature and specific cases involved. And compare different pieces of literature to illustrate their advantages and disadvantages, then explain the circuit oscillation problems that will exist in actual operation to propose solutions. Finally, this paper draws a conclusion that the oscillation can be reduced from two aspects: changing the additional phase shift after compensating the capacitance hysteresis or reducing the feedback depth. This is of certain significance to future research on circuit stability, so that it can be used in future production and manufacturing.

© 2023 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-8818/19/20230541

2. Analysis of stability of negative feedback amplifier circuit

2.1. Thornburgh diagram method

Assume that the negative feedback amplifier in question is not compensated and the feedback coefficient $\dot{F}$ is constant (the network is composed of pure resistance), then three-stage directly coupled amplifier circuit $\dot{A}$:

$$\dot{A} = \frac{10^5}{\left(1+j\frac{f}{10^3}\right)\left(1+j\frac{f}{10^4}\right)\left(1+j\frac{f}{10^5}\right)} \tag{1}$$

The Bode diagram of $\dot{A}$ is shown in Figure 1:

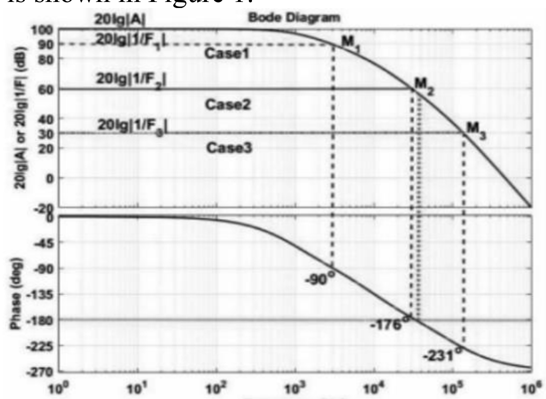

Figure 1. Byrd diagram of basic amplification circuit [3].

Let the amplitude frequency characteristic curve of $\dot{A}$ and horizontal line 201g|1/$\dot{F}$| intersect at point Mi, which meets amplitude condition $|\dot{A}\dot{F}|=1$ and 201g $|\dot{A}|-$ 201g $|1/\dot{F}|$ = 0 dB, and intersection points M1, M2 and M3 correspond to Case1, Case2 and Case3 respectively: F1 =$10^{-4.5}$、F2 = 10^{-3}、F3=$10^{-1.5}$. Although the traditional Bode diagram analysis method discusses stability through the phase shift of intersection Mi , which meets the self-excited oscillation amplitude condition, it does not give the value of $|1+\dot{A}\dot{F}|$. Therefore, it is difficult to analyze the feedback depth of the amplifier circuit.

2.2. Loop gain nyquist diagram analysis method

In the case of $0 \leq \omega < \infty$, draw the Nyquist curves corresponding to Case1, Case2 and Case3 respectively, and figure 2 can be obtained. The three Nyquist curves intersect the positive real axis at point N1:3.16, N2:100 and N3:3162, the Auxiliary real axis at point Li, the unit circle N (the center of the circle is (- 1, 0)) at point Qi, and the unit circle M (the center of the circle is (0, 0)) at point Mi, respectively, as shown in figures 3 and 4.

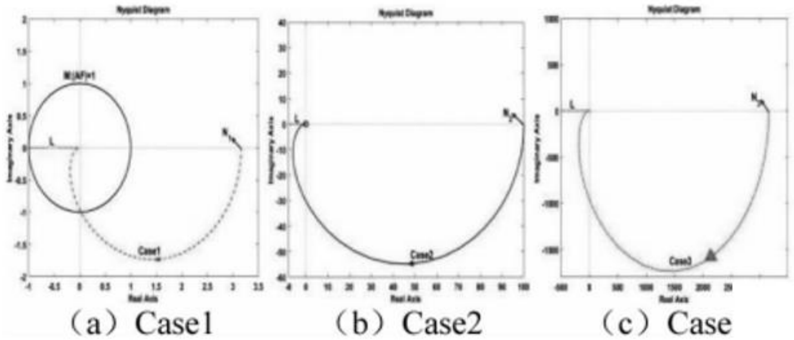

Figure 2. Loop gain Nyquist curve [3].

DOI: 10.54254/2753-8818/19/20230541

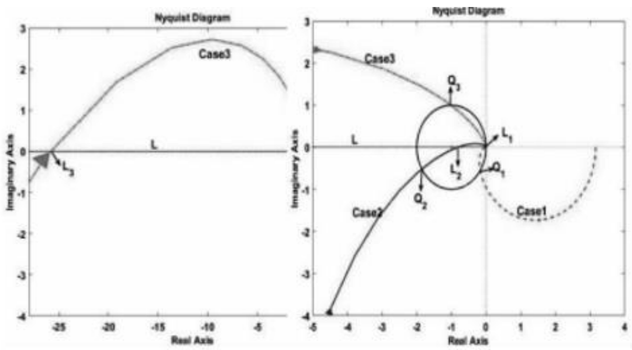

Figure 3. Nyquist curve of unit circle with (- 1, 0) center [3].

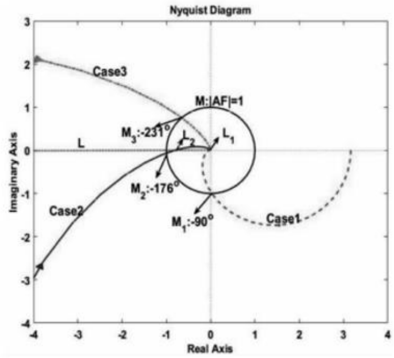

Figure 4. Nyquist curve of unit circle with (0, 0) center [3].

There are two stability analysis methods:

a. Under the condition of [0 °, - 360 °) for one cycle, in terms of the phase of the intersection point Mi between the unit circle with (0, 0) as the center and the loop gain Nyquist curve($\varphi_a+\varphi_f$) : if $0° \geq \varphi_a+\varphi_f > -180°$, the system is stable; If $-180° \geq \varphi_a+\varphi_f > -360°$, the system is unstable and self-excited oscillation; $\varphi_a+\varphi_f = -180°$ is the dividing point of stability and oscillation.

b. Compare the relationship between the unit circle and the intersection point Li of the negative real axis and the Nyquist curve of the loop gain to analyze: When the intersection point is in the unit circle, and far away from the self-excited oscillation point (- 1, 0), then the system is stable; When the intersection point is in the unit circle, the closer to the self-excited oscillation point (- 1, 0), the closer the system is to the edge of self-excited oscillation and instability; When the intersection point is on the unit circle, which is also the self-excited oscillation point (- 1,0), then the system is unstable and starts self-excited oscillation; When the intersection point is outside the unit circle, the farther away from the self-excited oscillation (- 1, 0), the more unstable the system is. At the same time, it is easier to self-excited oscillation. However, when analyzing the stability of the negative feedback amplifier circuit with the loop gain, the scheme draws the conclusion that it approaches the self-excited oscillation to make it unstable without giving the unstable range, which is not rigorous enough [3].

2.3. Analysis method of amplitude and phase margin

The analysis method of amplitude and phase margin improves the shortcomings of the first two methods, uses the loop gain frequency characteristic $20\lg = |\dot{A}\dot{F}|$ to define the stability of the amplification circuit, and obtains the margin range in Bode diagram and Nyquist diagram directly to judge the stability of the circuit. The result is more stable and the self-excited oscillation limit is clearer. When |AF| = 1, $20\lg|\dot{A}\dot{F}|=0$, the corresponding frequency is f_C; The frequency corresponding to $\phi_A+\phi_F = (2n+1)180°$is f_0. If f_0 does not exist, the circuit is stable without additional phase shift of lead and lag; If f_0 exists , when $f_0 > f_C$, the circuit is stable, when $f_0<f_C$,the circuit is unstable. In order to make the

DOI: 10.54254/2753-8818/19/20230541

circuit have enough reliability, the circuit amplitude margin G_m is defined: G_m=0 lg $|\dot{A}\dot{F}| \leq -10$ dB; Phase margin $\phi_m = 180 - |\phi_A + \phi_F| \geq 45°$ [4]. As shown in Figure 5:

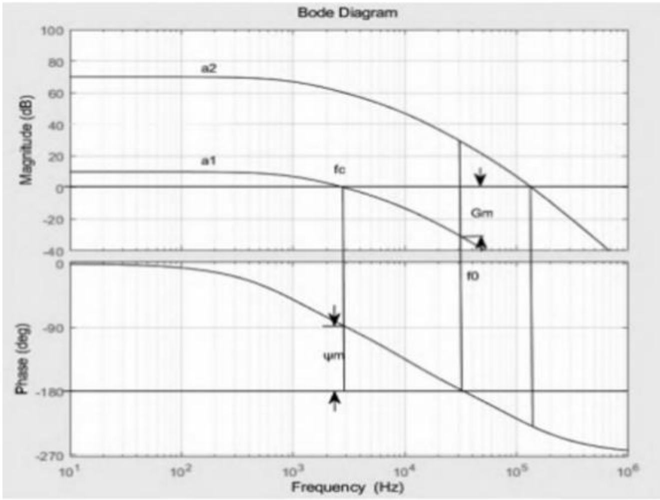

Figure 5. Bode Diagram of Loop Gain Stability Margin [4].

3. Oscillation of negative feedback circuit and its solutions

3.1. Oscillation of negative feedback circuit

In the actual operation of a negative feedback circuit, the introduction of negative feedback may make the circuit unstable, which may cause an overshoot of the time domain signal or oscillation of the circuit. The closed loop amplification factor of the negative feedback amplification circuit is $A_f = \frac{A}{1+AF}$, where AF is called loop gain. The stability of a system mainly depends on the way AF transforms with frequency. In reality, AF is a complex number with amplitude and phase angle. When AF phase angle is 180 °, AF is a negative real number. If | AF |=1, then 1+AF=1, and the closed-loop amplification factor is A_f will be equal to infinity. At this time, a small input will cause a violent response. Since the negative feedback becomes positive feedback, the feedback will cause a larger output, so there will be an oscillation.

3.2. Causes of oscillation

Load capacitance is one of the reasons for the oscillation. Here we need to understand the open-loop output resistance of the integrated operational amplifier. The ideal operational amplifier output resistance is zero, while the actual operational amplifier will have an output resistance. The open-loop output resistance of the OPA227 simulation model is about 20Ω. From this, we can calculate the open-loop gain A, and there is an additional pole fp=1/2πRoCL=1/2π×20×10^{-6}≈8KHz, which is far less than the unit gain bandwidth of OPA227, 8MHz.

3.3. Stability judgment after oscillation

Analyze the position of fp through simulation, remove the input signal at the same phase end, and ground the same phase end. The circuit is shown below. Introduce L1 to disconnect the AC feedback loop, and introduce C1 to connect the test signal to the reverse input. To the circuit Beta= （1/F） =Vo/VFB, A=Vo/V-. Firstly, use the software's AC analysis function to obtain Vo, VFB, and V - curves, and then conduct to obtain A and Beta, that is, (1/F) curves. When |AF|=1, there is |A|=|Beta|, that is, the intersection of amplitude frequency characteristics. According to the circuit stability judgment, when a circuit phase domain is Φm > 45°, the negative feedback amplifier circuit is considered to have reliable stability [5].

DOI: 10.54254/2753-8818/19/20230541

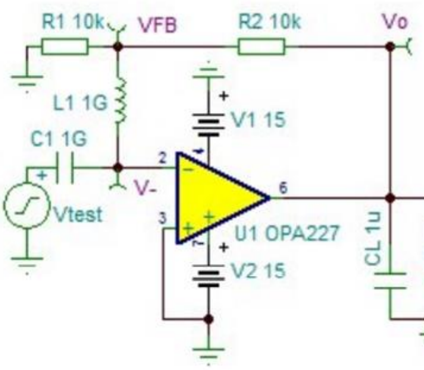

Figure 6. Open loop amplification circuit [5].

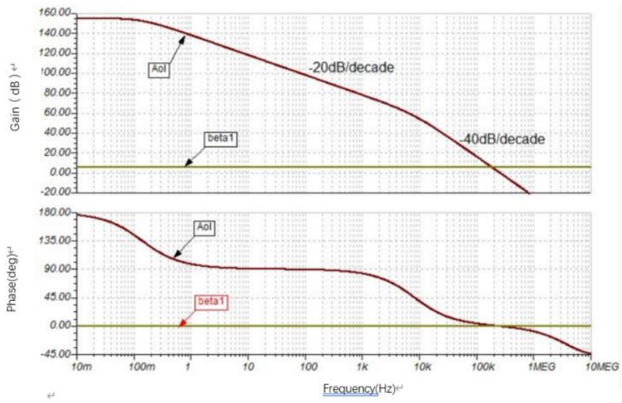

Figure 7. Open loop Baud diagram of negative feedback amplifier circuit (Ao1 in the figure is A, beta 1 is 1/F) [5].

3.4. Elimination of self-excited oscillation

The following figure shows the negative feedback circuit diagram of virtual experiment as an example. The typical value of the magnification of OP07 operational amplifier is A=4 $\times 10^5$, the typical value of unit gain bandwidth GBW=0.6MHz, resistance R2=R3=20 kΩ, R1=100 k Ω, R4=10 kΩ, set the initial value of variable capacitor C1=160pF, and the initial resistance of potentiometer Rf=20k Ω.

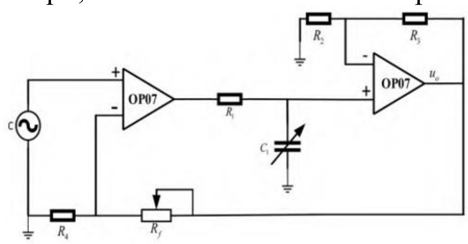

Figure 8. Negative feedback amplification circuit [6].

Its forward transfer function is

$$A_{VO}(jf) = \frac{A}{1+jfA/GBW} \times \frac{1}{1+jf \cdot 2\pi R_1 C_1} \times \frac{1+R_3/R_2}{1+jf \cdot (R_2+R_3)/(GBW \cdot R_2)} \tag{2}$$

The forward transfer phase shift is

$$\varphi_{AV}(jf) = -\arctan\left(\frac{f \cdot A}{GBW}\right) - \arctan\left(f \cdot 2\sqcap R_1 C_1\right) - a\,rctan\left(\frac{f \cdot (R_2+R_3)}{GBW\, R_2}\right) \tag{3}$$

The feedback channel is composed of R4 and Rf, and the feedback transfer function of the negative feedback amplification circuit is:

$$F(jf) = R_4/(R_4 + R_f) \tag{4}$$

Phase shift of feedback channel: $\varphi_F(jf) = 0$

In addition, the negative feedback amplifier circuit must meet the phase balance conditions and the starting conditions to generate self-excited oscillation, that is

$$\varphi_{Av}(jf) + \varphi_{F=}(jf) = -\pi \tag{5}$$

$$|A_{vo}(jf)F(jf)| > 1 \tag{6}$$

Capacitance lag compensation or reduction of feedback depth can be used to eliminate self-excited oscillation. For negative feedback amplifier circuit, self-excited oscillation can be eliminated as long as the phase balance condition or the oscillation starting condition is not met. Under this condition, negative feedback amplifier circuit will not produce oscillation.

a. Capacitance hysteresis compensation changes additional phase shift

Change the value of variable capacitor to C1=1.6pF. According to Formula (3) and Formula (5), f=546kHz at this time. Substituting f=546kHz into Formula (2) and (6), we can see that the open-loop amplification factor is 0.93, F=0.31 < 1. According to the conditions for generating self-excited oscillation, the phase balance condition Formula (5) and the starting condition Formula (6) are met simultaneously, and the negative feedback amplifier circuit will generate self-excited oscillation. The calculation results show that the two conditions cannot be met at the same time, so the negative feedback amplifier circuit under this condition will not produce self-excited oscillation.

b. Reduce feedback depth

Keep the variable capacitor value C1=160 pF unchanged. At this time, we can know from formula (3) and formula (5) that f=54.6 kHz. Substitute f=54.6 kHz into formula (2), and open loop amplification factor A_{vo}=3.88, let $A_{vo}F < 1$, calculated Rf > 28.8kΩ, under this condition, negative feedback amplifier circuit does not produce self-excited oscillation [6].

4. Conclusion

This paper mainly discusses the stability of the negative feedback amplifier circuit. On the basis of theoretical analysis, it analyzes and solves the problems that may occur in the actual operation, and draws the conclusion that the oscillation can be reduced by changing the additional phase shift after compensating the capacitance hysteresis or reducing the feedback depth. However, this paper does not give specific solutions in combination with experiments, which is needed to be improved, future research can study further in these two aspects to ensure the maximum stability of the circuit.

References

[1] Fang Weiqiang, Ma Jun, Chen Boxing. Performance optimization of negative feedback amplifier circuit based on block diagram analysis [J]. Modern Electronic Technology, 2021,44 (08): 35-39. DOI: 10.16652/j.issn.1004-373x.2021.08.008

[2] Xu Xiaoguang, Huang Honghong, Zhao Ziyi. Stability analysis and correction method of negative feedback amplifier circuit based on simulation [J]. Journal of Langfang Normal University (Natural Science Edition), 2022,22 (02): 26-30

[3] Cao Dianguo, Li Cong, Wu Yuqiang. Analysis of negative feedback amplifier circuit based on loop gain [J]. Journal of Electrical and Electronics Education, 2020,42 (01): 75-78

[4] Zhao Chunyan, Zhou Xiaoyan, Liang Qingqing. Stability analysis and design of negative feedback amplifier circuit [J]. Journal of Electrical and Electronics Education, 2022,44 (03): 144-145

[5] Guo Zhiyuan. Stability analysis of negative feedback amplifier circuit [J]. Journal of Gansu Radio and Television University, 2019, 29 (03): 74-78

[6] Ding Shoucheng, Xiao Limei, Yan Ke, Wang Guifeng. Experiment on the Performance Analysis of a Negative Feedback Amplifier Circuit Combined with Virtual Reality [J]. Journal of Electrical and Electronics Education, 2022,44 (01): 181-184