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Design of Two-Stage Operational Amplifier Based on IC Design

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Abstract: Modern integrated circuit technology includes analog integrated circuit design and digital integrated circuit design. Analog circuit refers to the circuit used to transmit, transform, process, amplify, measure and display analog signals. Analog signals are electrical signals that change continuously. Analog circuit is the basis of electronic circuit. It mainly includes amplification circuit, signal operation and processing circuit, oscillation circuit, modulation and demodulation circuit and power supply. Compared with single-stage amplifier, multi-stage operational amplifier has higher magnification.

Keywords: IC Design; Analogue Circuit; Operation Amplifier; Common Source; Multistage

1. Introduction

1.1 Integrated circuit technology

Integrated circuit, abbreviated as IC; As the name suggests, it is a circuit with specific functions that integrates a certain number of common electronic components, such as resistors, capacitors, transistors, and so on, as well as the wiring between these components through semiconductor technology. It is a new type of semiconductor device developed from the late 1950s to 1960s. It is an electronic device that integrates the semiconductor, resistors, capacitors and other components required to form a circuit with certain functions and the connecting wires between them on a small silicon wafer through semiconductor manufacturing processes such as oxidation, lithography, diffusion, epitaxy and aluminum evaporation, and then soldered and encapsulated in a shell[1]. Its packaging shell has many forms, such as round shell type, flat type or dual in-line type. Integrated circuit technology includes chip manufacturing technology and design technology, which is mainly reflected in the ability of processing equipment, processing technology, packaging and testing, mass production and design innovation.

Integrated circuits include analog integrated circuits and digital integrated circuits. The most important part of integrated circuit is transistor, as well as analog integrated circuit. But the analog IC uses the amplification of transistor, while digital IC uses the switching function of transistor. Digital IC is used to generate, amplify and process various digital signals. Analog integrated circuit mainly refers to the integrated circuit composed of capacitance, resistors and transistor, which is integrated to process analog signals[2].

1.2 Amplifier

Amplifier circuit is one of the most widely used analog circuits. Operational amplifier (OP AMP) is a circuit unit with high magnification. Because it was used in analog computers in the early stage to realize mathematical operation, it was named "operational amplifier"[3]. The function of operational amplifier is to amplify the input analog signal. It usually includes a positive input, a negative input, an output and power supply. Considering that the voltage gain of operational amplifier is very large, ranging from hundreds to tens of thousands of times, when operational amplifier is usually used, its output end will be connected with its inverting input end to form a negative feedback circuit. This negative feedback circuit can ensure the stable operation of the circuit.

Integrated operational amplifier circuit is a direct coupled multistage amplifier circuit. It is the product of the combination of circuit, circuit system and components by using the integrated technology of semiconductor. Due to the use of integrated technology, the consistency of parameters of adjacent components can be good, and the complex circuit with multiple transistors can make its performance very superior. There are different models of integrated operational amplifiers, but the most commonly used is the general-purpose integrated operational amplifier. Its internal circuits are generally differential input stage, intermediate stage and complementary output stage, with a variety of current source circuits.

1.3 Importance of integrated circuit

Now, integrated circuit has played a very important role in all walks of life and is the cornerstone of modern

information society. As for integrated operational amplifier circuit, it can be seen not only in industrial and civil electronic equipment, such as tape recorders, televisions, computers and so on, but also in military, communication, remote control and so on [4]. The reasons are integrated circuit has the advantages of small volume, light weight, less outgoing lines and welding points, long service life, high reliability and good performance. At the same time, it has low cost and is convenient for large-scale production.

1.4 The target of the experiment

In this paper, we briefly introduce the background knowledge about MOSFET and Operation amplifier; and construct a model of a two-stage operational amplifier. The two-stage amplifier involved in this paper is a comprehensive amplifier, including three parts: The first stage with a common source amplifier with mirror current source load, the second stage with a simple common source amplifier, and a miller compensation capacitor. The circuit of the two-stage amplifier was designed and its related parameter was initially verified by using cadence virtuoso. The goal is to achieve a magnification of more than 6000

2. Design of The Circuit And Its Principles

2.1 Overall circuit

The principle of a two-stage common source amplifier with differential input and single output is shown in Figure 1. The first stage is a common source amplifier with mirror current source load, and the second stage is a simple common source amplifier. For the first stage, M3 and M4 are required to have the same aspect ratio, and M1 and M2 are required to have the same aspect ratio. Only one transistor in the active load is connected through a diode, and the circuit is asymmetric. The half loop method is no longer used.

Add Miller compensation capacitor CC between point a and point B and pull the two poles apart through the feedback of the compensation capacitor.

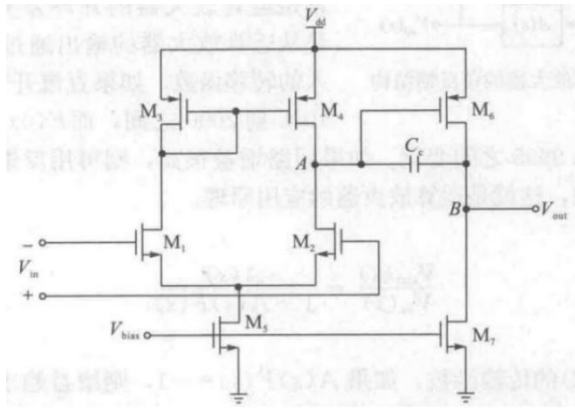

Figure 1: Two stage common-source amplifier with differential input and single output

2.2 NMOS

MOSFET is the most basic and important component in amplifier design. NMOS has drain, source and gate. Power grounding. The I-V characteristic curve of NMOS can be obtained by changing the DC voltage of drain and gate input and measuring the drain input current. The design of the amplifier mainly uses the characteristics of the saturation region of MOS transistor

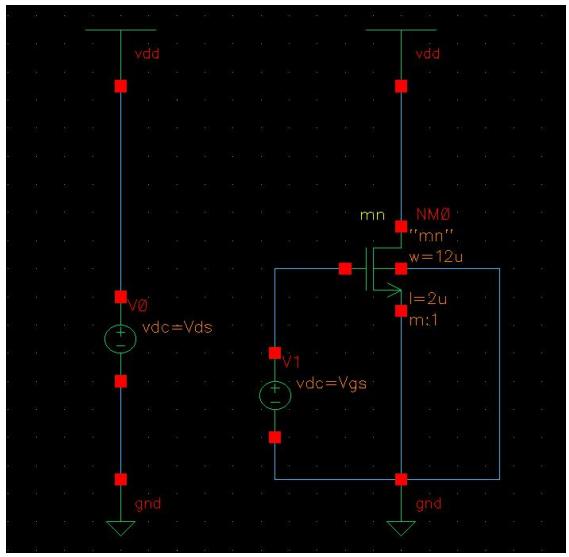

Figure 2：test circuit for NMOS

2.3 Commom-source amplifier

A PMO and a NMO are connected in series. The source of PMO and the drain of NMO are connected together. The rule of series connection of transistor and resistance is the same, the equivalent resistance increases, and the current does not change.

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Through the saturated equation:

$I_{DS} = \frac{1}{2}K' \frac{W}{L}(V_{GS} - V_T)^2(1 + \lambda V_{DS})$,

We can get the current expressions of NMOS and PMOS respectively. Because $I = I_1 = I_2$. Then we can get an amplified V_{out}

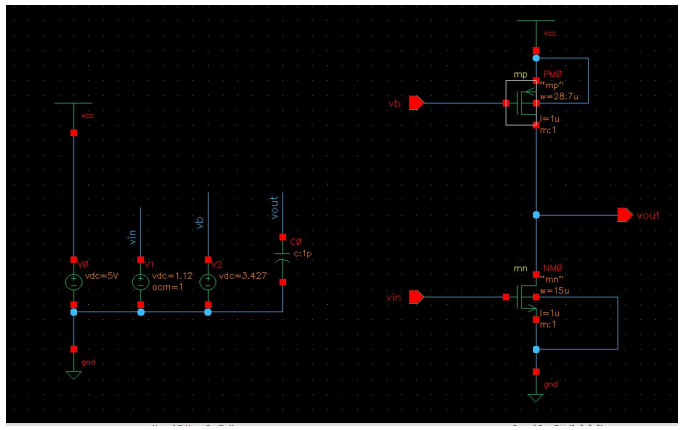

Figure 3: common source amplifier

2.4 Miller compensation capacitor

The circuit of two-stage operational amplifier has two high resistance nodes A and B, that is, the circuit has two main poles. Since the frequency distance between the primary and secondary primary poles of the two-stage operational amplifier is relatively close, the phase margin is reduced. In order to make the operational amplifier work stably, the Mille feuille compensation technology is used. Generally, a miller compensation capacitor C is added between point A and point B, and the two poles are pulled apart through the feedback of the compensation capacitor.

3. Simulation And Result Analysis

Integrated circuit design includes analog circuit design, digital circuit design and device layout design. In the past, we can design analog circuit using Ltspice, design digital circuit using Vivado or Quartus, and design layout using Klayout.

This experiment, a new software was used for integrated circuit design. It is cadence virtuoso, which can achieve all functions above and can easily convert the circuit scheme into layout.

3.1 Simulation environment

First, set the analysis variable and the output. The AC analysis was set from 1 to 1000000000, Every ten times is an interval

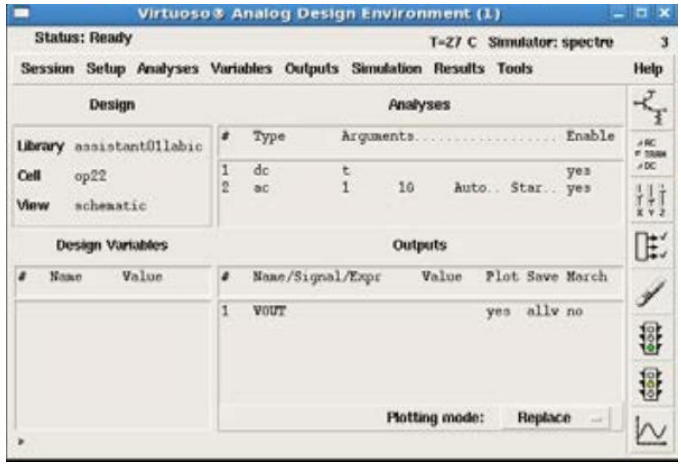

Figure 4: Analysis and Output

Then, Select process library in sequence. Process corn starts from tt. Totally five process corners, including tt, fs, sf, ss, ff, all need to be used respectively.

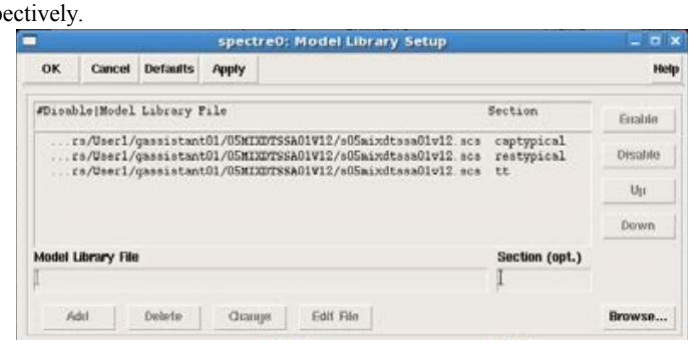

Figure 5: process library and process cornes

Last, click results->print->dc operating point, select the NMOS and PMOS to be checked, and ensure that the region value is 2. At this time, the MOS tube is located in the saturation region.

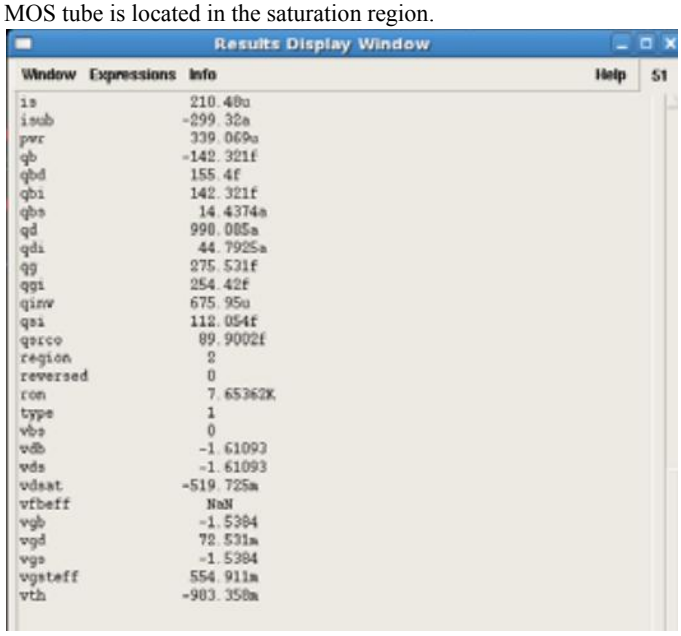

Figure 6: Saturation zone test

3.2 Overall circuit and layout

The circuit and the layout of the two-stage operation amplifier are shown in figure 7, figure 8, and figure 9 respectively

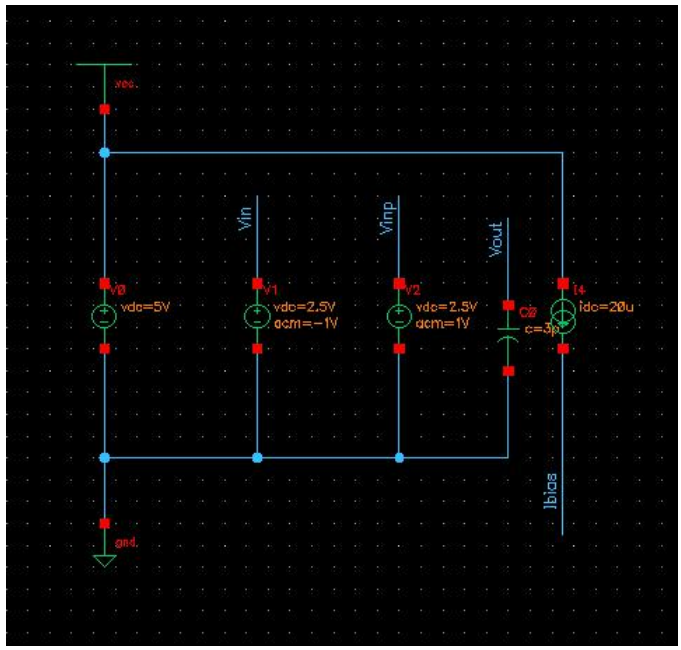

Figure 7: the signals of the amplifier

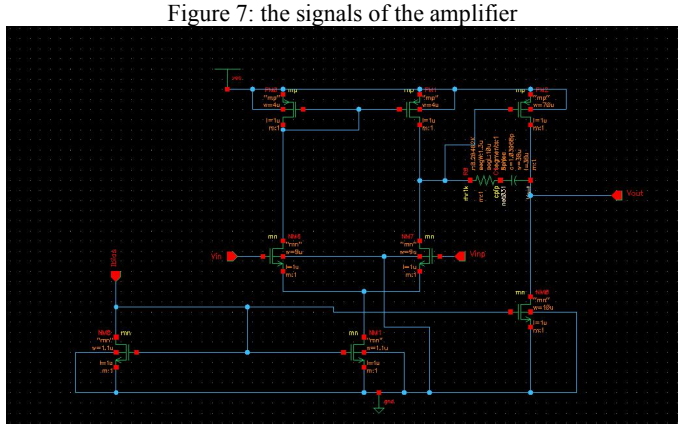

Figure 8: the main part of the amplifier circuit

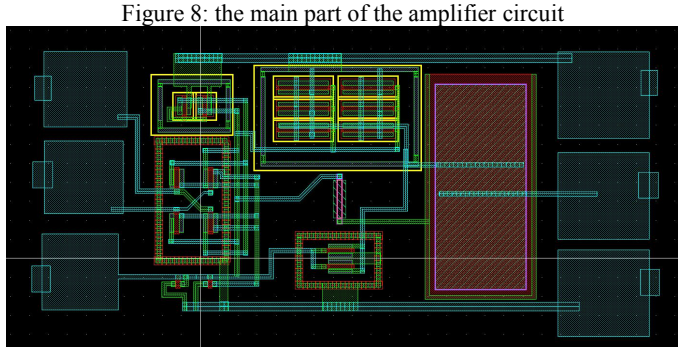

Figure 9: the layout of the amplifier

3.3 Experimental result and analysis

The results are shown below, and we have successfully designed a two-stage operational amplifier with a magnification higher than 6000 times.

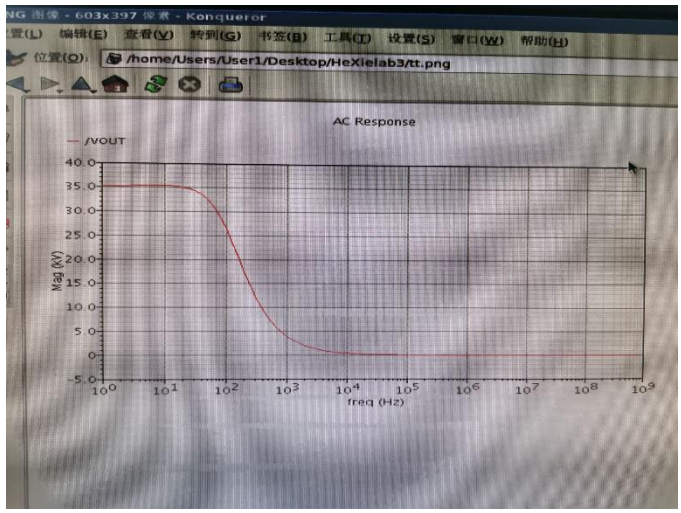

Figure 10: library corner tt

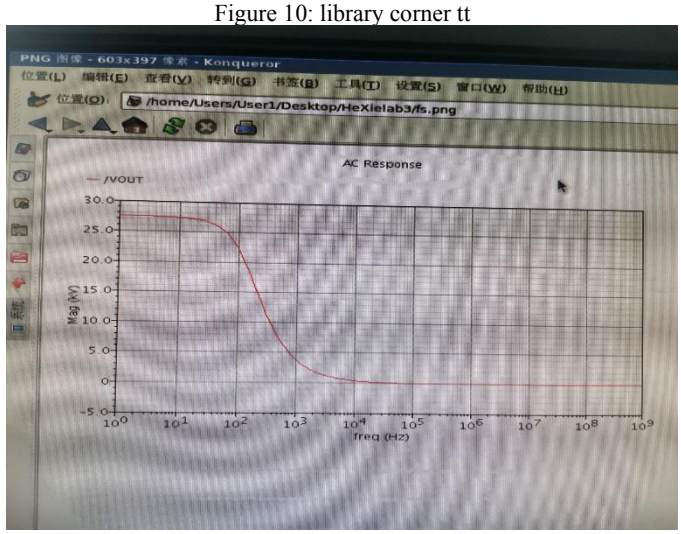

Figure 11: library corner fs

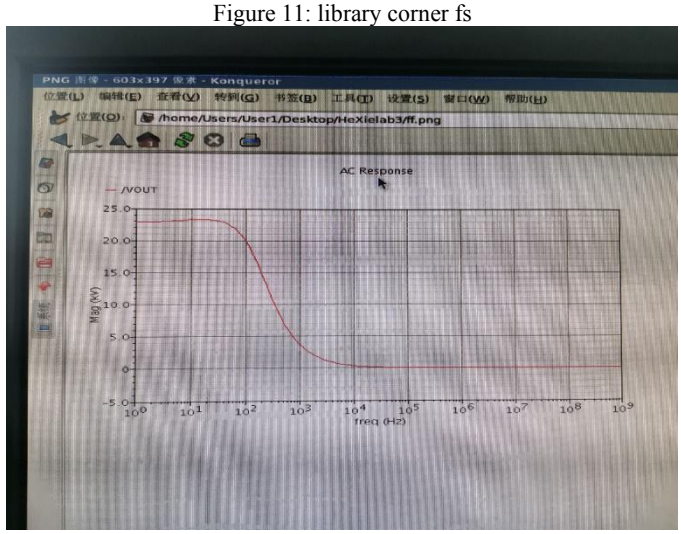

Figure 12: library corner ff

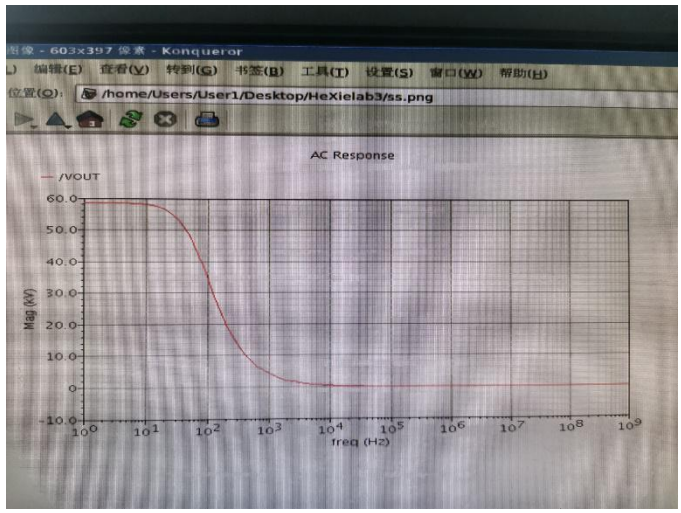

Figure 13: library corner ss

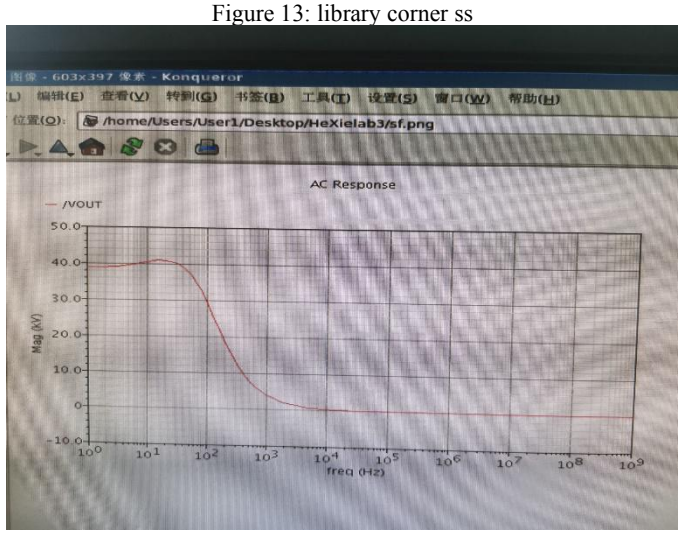

Figure 14: library corner sf

The common mode rejection ratio (CMRR) results are as follows. When measuring this parameter, the inverter input and non-inverter input have the same common mode input voltage, and the inverter input is connected to the output

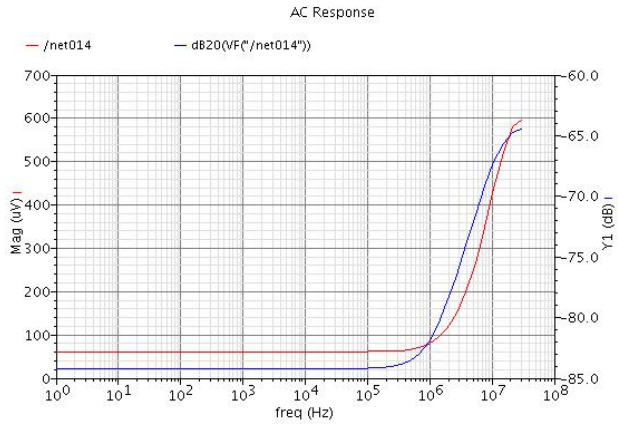

Figure 15: CMRR

Form the figure, the CMRR is between 80dB to 85db, then we can know that the gain of differential signal is more than 10000 times larger than the gain of the common-mode signals. So, the output voltage can successfully reflect the amplify of the differential signals.

4. Conclusion

In general, this experiment is successful. We have successfully designed a multi-stage operational amplifier that can amplify the differential mode signals more than 6000 times by using MOSFET. In the design process, in addition to

designing the circuit diagram structure and layout, we also need to adjust some parameters, such as the channel width and aspect ratio of MOSFET. We can use the current saturation equation of MOSFET to roughly determine the parameter range we need to adjust through calculation. However, I find that when we change the selection of process corners in the model library, the simulation results are different, so it is difficult for us to calculate accurate parameters. In the end, we used the software to get the desired results, but the specific differences between the five process angles are still worth exploring. We need to know the specific process reasons for the different results.

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