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The Research of Integrated Circuit Design Technology

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Abstract. This article discusses the fundamentals of analogue integrated circuit design and construction, as well as the operation and some basic models of MOS transistors. It also provides a thorough introduction to the CMOS, PMOS, and NMOS structures, as well as the benefits and drawbacks of each. Additionally, operational and differential amplifiers are introduced, along with some examples of their uses. While attending summer school, I also learned how to simulate the SPEICE model using the computer program CoolSPICE. The SPEICE model is a literal description of a circuit component that theoretically predicts the behavior of that component under various conditions. The article ends with forecasts and suggestions regarding the future evolution of analog circuits and their potential effects on society.

Keywords: transistor, amplifier, common-source, common-gate, common-drain topologies.

1. Introduction

At this stage, the variety of electronic products has been very broad, and the field of electronic information is developing rapidly, such as more convenient communication systems, online taxi software, and real-time positioning of children's watches anti-theft system. Electronic information technology and the development of electronic devices for the whole machine, two are mutually reinforcing and mutually constraining relationships. The need for integrated circuit design is also evident, as the manufacture of highly sophisticated machines cannot be separated from it. In addition, the Internet of Things applications have entered the practical application stage, sensors in the upstream of the Internet of Things industry chain, will be the entire Internet of Things industry in the largest demand and the most basic link. At present, approximately 40 countries are now working on development, with more than 5 thousands companies producing sensors, which have more than 20,000 kinds of products. The market for sensors in China has been growing continuously in recent years, with a growth rate of more than 15%. It is anticipated that the creation and fabrication of electronic components will soon become simpler, faster, and less expensive thanks to increasingly advanced electronic information technology.

This article introduces some of the basics of the electronic system, and the design of integrated circuits, including the different types and the construction of MOS, the basic composition, and the role of amplifiers. The different types of MOS tubes can be used appropriately on different machines because of their different characteristics. For example, triodes have some features: small, lightweight, no noise, long life, high capacity, endure with high voltage, high current, high power, and cheaper but are more power-efficient, and commonly used as AC switches. While MOS tubes are more expensive but more energy-efficient, which mostly used as electronic switches in many kinds of machines, e.g. motor drives, electric drilling tools, industrial switching power supplies, new energy sector, photovoltaic inverters, charging piles, drones, transport sector, and vehicle inverters, etc.

2. Literature review

2.1 Metal Oxide Semiconductor (MOS)

MOS tubes are metal oxide semiconductor type field effect tubes, which belong to the insulated gate type.

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To facilitate the generation of an electric field, scientists have invented a structure that looks like a sandwich. The top layer of this structure is a metal, usually an aluminum compound, the middle layer is an oxide, usually silicon oxide, and underneath is a P-type semiconductor, also referred to here as a P-type substrate. Such devices are known as Metal Oxide Semiconductor, or MOS for short.

MOS is also divided into NMOS and PMOS. An electric field is added between the metal layer and the substrate, causing electrons to accumulate under the oxide and form an inversion layer. Originally a P-type substrate, an electron layer appears, which is also called a "trench" in China, and is also known as an N-channel.

The NMOS is created like this: the N-type electrodes are etched on both shoulders of the P-type substrate, and then processed this material The metal layer is always called the G-pole, or gate; The end with the higher N doping concentration is called the S-pole or source, and the end with a slightly lower doping concentration is called the D-pole or drain. In an N-type Semicon, there are electrons in the channel, and because there is an electron supply at the source, it can create a current path.

The electrons flow from S to D under the force of the electric field created by the external bias, and since the current is defined in the opposite direction to the flow of electrons, the current flows from D to S. Therefore, the point at D is higher than the point at S. For devices with an N-type substrate, we have to apply an electric field to create a ‘hole’ region, i.e. a P-channel, so-called PMOS, where the ‘hole’ region needs to be generated at a low level, so the potential at the G-pole is lower than at the source. P-channel is flowing with "holes", so the current direction is from the S-pole to the D-pole, so the potential at the S-pole is higher [1].

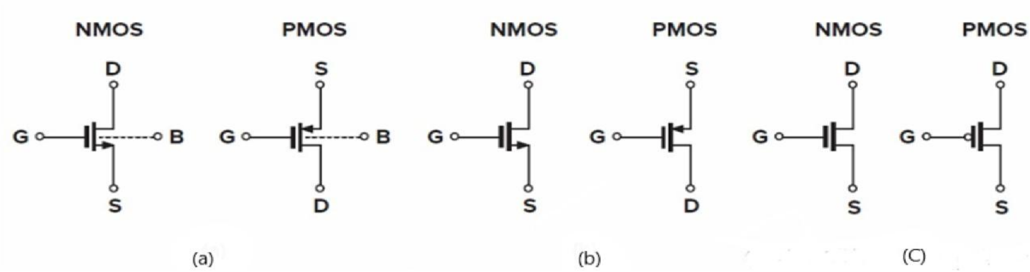

Fig. 1 MOS symbol

1.1.1 N-metal-oxide-semiconductor transistor

Two highly N+ doped regions are built on a low-doped P-type silicon substrate and two electrodes were labeled with aluminum metal as drain D and source S, respectively. The semiconductor was then covered with a very thin silicon dioxide (SiO2) insulating layer, and the aluminum electrode was placed on the drain-source insulating layer as gate G. Electrode B was also placed on the substrate to form an amplified MOSFET tube with channel N. It is also known that the source and substrate of a MOS tube are usually connected together.

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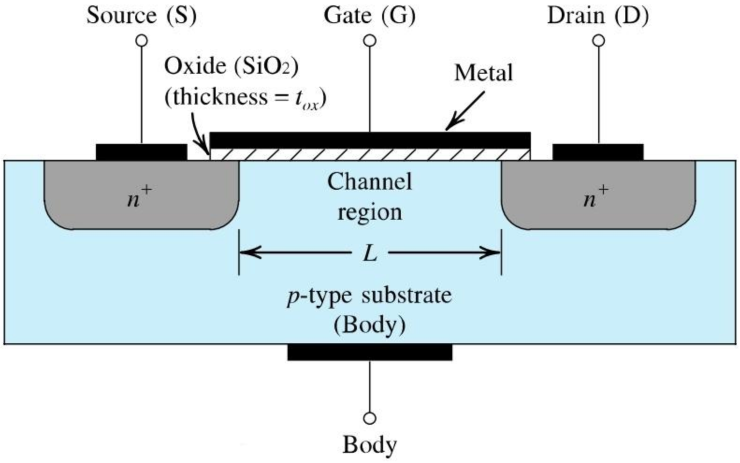

Fig. 2 NMOS physical structure

(1) The role of vGS in controlling iD and the trench

① The case of vGS=0

Enhanced MOS tubes have two back-to-back PN junctions between the drain d and the source s. When the voltage from the gate to the source vGS = 0, even if the voltage from the drain to the source vDS is added, and regardless of the polarity of vDS, the PN junction is always in the reverse state, there is no conductive channel between the two sources. There would be no conducting channel between the drain and the source, so the drain current iD≈0 right now.

② The case of vGS ＞ 0

If vGS>0, between the substrate and the gate, an electric field will be generated in the SiO2 insulating layer. The electric field is directed perpendicular to the semiconductor surface from the gate to the substrate. This electric field repels holes and attracts electrons.

In a P-type substrate, the holes near the gate are ejected, leaving immobile gaseous ions (negative ions) behind, forming a dull layer. Electron attraction: Electrons in the P-type substrate are attracted to the surface of the substrate.

(2) The impact of vDS on iD

When vGS > VT and is a definite value, the effect of the drain-source voltage vDS on the conducting channel and current iD is similar to that of a junction type field effect tube.

The voltage drop along the channel generated by the drain current iD makes the voltage between the points in the channel and the gate no longer equal, the voltage near the source end is the largest, where the channel is the thickest, while the voltage at the drain end is the smallest, the value of vGD = vGS - vDS, so here the channel is the thinnest. But when vDS is small (vDS <vGS − VT), it has little effect on the channel, then as long as vGS is certain, the channel resistance is almost certain, so iD with vDS is approximately linear change.

As vDS increases, the channel near the drain becomes thinner and thinner, and when vDS increases to the point where VGD = vGS - vDS = VT (or vDS= vGS - VT), the channel appears pre-clamped at the drain end. Continuing to increase vDS further, the pinch-off point will move towards the source. Since almost all of the increase in vDS lands in the pinch-off region, iD barely increases with increasing vDS, and the tube enters the saturation region where iD is determined almost solely by vGS. As figure2.3 shown below [2].

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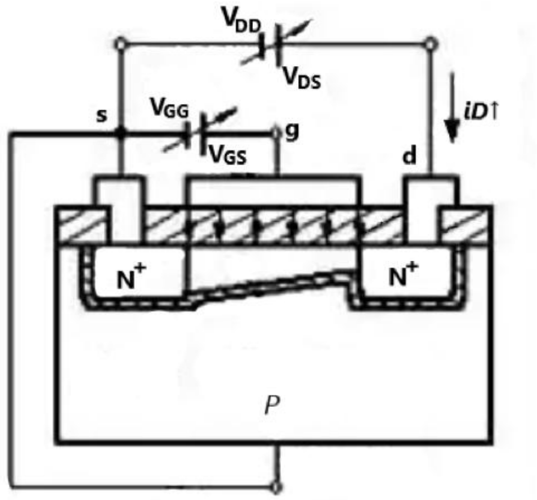

Fig. 3 Schematic of the principle

1.1.2 P- metal-oxide-semiconductor transistor

The operating principle of PMOS is similar to that of NMOS. Since PMOS is an N-type silicon substrate in which most of the charge carriers are electrons and few charge carriers are holes, and the doping type in the source-drain region is P-type, PMOS operates under the condition that a negative voltage is applied to the source gate, i.e., a negative voltage is applied to the PMOS gate, inducing a moving positively charged hole and a depletion layer with a constant positive charge in the substrate, regardless of the applied voltage. Regardless of the effect of the charges existing in the silica, the number of positive charges induced in the substrate is equal to the number of negative charges on the PMOS gate. When a strong inverse pattern is reached, the positive charge holes at the source reach the drain via a conducting P-channel under the influence of a negative drain-source voltage with respect to the source, creating a source-drain current from source to drain. Again [3], the more negative VGS is (the greater the absolute value), the lower the on-resistance of the channel, the higher the current value.

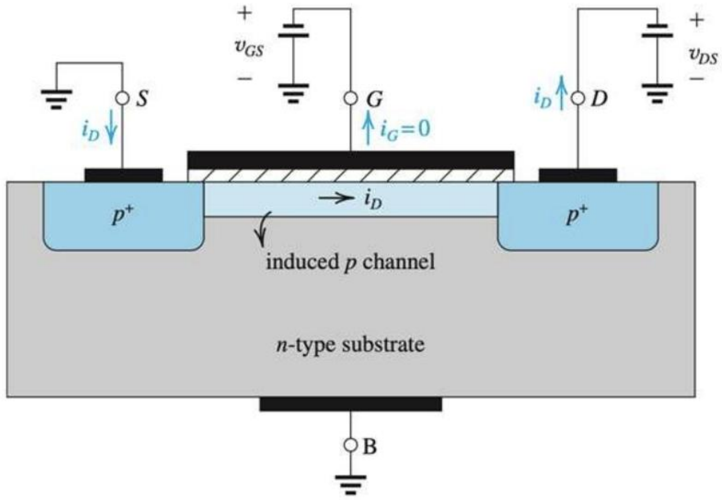

Fig. 4 2.1.2 P- metal-oxide-semiconductor physical structure

1.1.3 C- metal-oxide-semiconductor transistor

CMOS circuits are complementary MOS circuits consisting of two types of tubes, NMOS and PMOS. There are two advantages of CMOS: Low cost due to large-volume digital integrated circuits integrated into high-density digital circuits.

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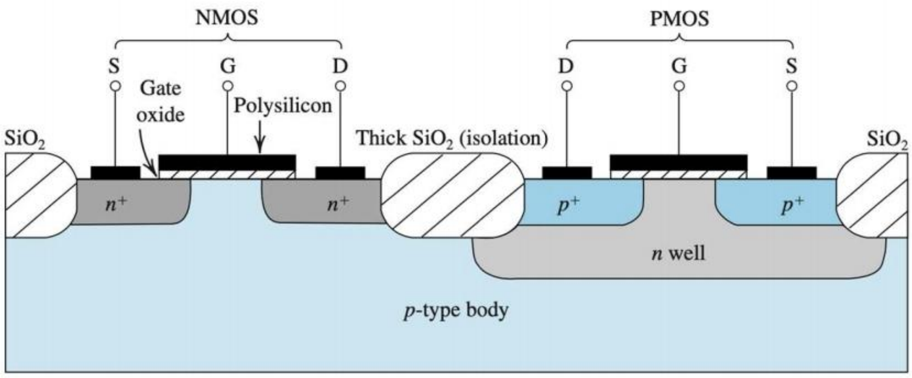


Fig. 5 CMOS physical structure

However, what we normally call CMOS is a technique used to manufacture large-scale integrated circuit chips or a chip manufactured with this technology, a read-write RAM chip on the computer's motherboard. Because of the read-write feature, this chip is used on the computer motherboard to store data after the BIOS has set the computer hardware parameters, this chip is simply used to store the data. There are three areas where CMOS is commonly used, the first being for computer information storage. The second is in the field of digital imaging, where chapter 2.1.3 C-metal-oxide-semiconductor has been developed as a low cost sensor technology, and where the main sensor used in the digital products available on the market is either CMOS or CCD, and the third is in the more specialized field of integrated circuit design and manufacturing, which is the area we will focus on in this article.

2.2 Amplifier

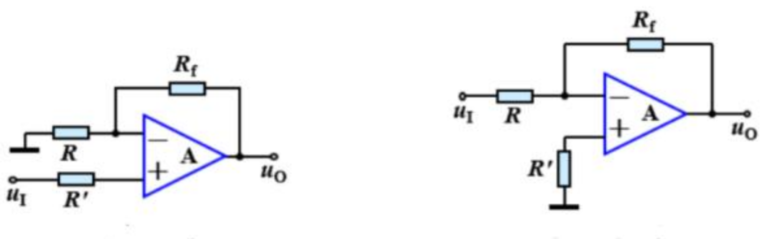
One of the roles of an operational amplifier is voltage gain. Voltage gain expresses the amplification capacity of an amplifying circuit for an input signal and the expression used is the decibel expression, which is defined as [4]

$$Gu = 20\lg (Uo/Ui) = 20\lg Au \quad (1)$$

1.1.4 Integrated operational amplifier

Operational amplifier is a kind of high performance direct coupled amplifier used for operation, it can not only add, subtract, integrate, differentiate and logarithm the signal, but also compare, detector, sample and hold, active filter and other processing of the signal, A/D, D/A, V/f conversion of the signal and generate various sine, square and triangle waveforms. The operational amplifiers are widely used in computers, automatic control, measurement technology, instrumentation and everyday life. When different linear or non-linear components are externally connected to form a negative feedback circuit, a variety of specific functional relationships can be flexibly implemented. It is also an essential part of the analogue circuit.

The following pictures show four typical arithmetic circuits [5].



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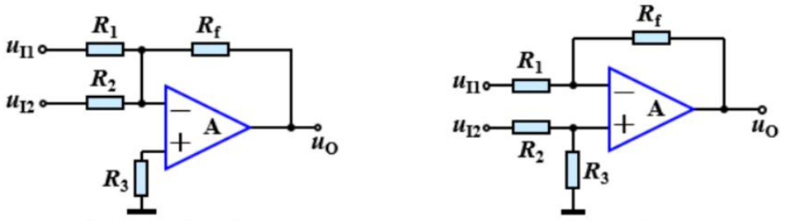
(a)Co-Phase Amplification Circuit (b) Inverted amplifier circuit



(c) The inverse add method circuit (d) Subtraction circuits

Fig. 6 Four basic operational amplifier circuits

1.1.5 Differential amplifier

A differential signal is a group of signals with the same amplitude and opposite phase. In fact, the earliest amplifier should belong to the differential amplifier, strictly speaking, its full name is full differential amplifier, the amplifier in addition to the input pair of differential signals, the output is also a pair of differential signals, and need two identical feedback loop, such an amplifier if the two feedback loops do not match, will bring a large second harmonic distortion.

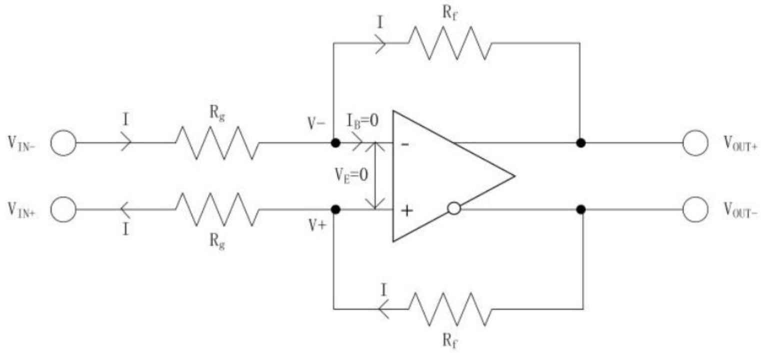


Fig. 7 closing the feedback loop of a fully differential amplifier

In a fully differential loop, there are no in-phase or anti-phase loops, and both feedback loops are inverted. Assuming that the op-amp is an ideal op-amp, i.e. the input detuned voltage ($V_{OS} = V_E = 0$), the voltage equation can be derived from the feedback loop as follows [6]:

$$\begin{aligned} IR_g + V_- = V_{IN}, \quad & IR_g =- V_{OUT+}, \\ -IR_g + V_+ = V_{IN+}, \quad & -IR_g =- V_{OUT-}, \end{aligned} \tag{2}$$

Among them,

$$V_{IN-} =- V_{IN+} =- V_{IN},\ V_{OUT-} =- V_{OUT+} =- V_{OUT},\ V_- = V_+ \tag{3}$$

The final result is,

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_f}{R_g} \tag{4}$$

3. Prospect

The future development of integrated circuits will bring many advances in various fields, making life scenarios smarter, communication more remote and convenient, and more cool new electronic devices, among which I think the most interesting and promising is the development of the medical field.

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Healthcare is a big market, and according to market research firm Sullivan (Frost & Sullivan), the global healthcare industry will reach more than US$2 trillion in revenue, with very promising growth rates ahead. The global medical device market is hundreds of billions of dollars in size, and new medical solutions represented by digital health are the main drivers of growth in the medical device market, the brightest of which are wearables and the Internet of Medical Things. Market Research estimates that the global healthcare IOT market will reach $136.8 billion. In the future, we are committed to building wearable medical devices with even lower power consumption, high-precision sensor technology and sensor fusion. Because the medical Internet of Things will become increasingly popular, networking of device information becomes a necessity. In particular, with the new coronavirus pandemic, more patients prefer to achieve diagnosis treatment and rehabilitation monitoring of common diseases at home, which has led to unprecedented growth in remote diagnosis and virtual care. In the future, remote diagnosis, remote nursing and remote surgery will become more common, and the healthcare scenario will require a more reliable, complete, real-time and efficient network environment. More sophisticated sensors are also needed, and this cannot be achieved without our more sophisticated integrated circuit designs.

Fig. 8 Use of circuit equipment and possible future developments

Acknowledgements

Thanks to this course, not only did I learn about basic circuit devices, but I also learned about the design of some simple integrated circuits, including components such as transistors, resistors, capacitors and inductors. I also learned how to choose the right devices to achieve the right power consumption and the required functionality of the design. The teacher introduces the simplest of analogue circuits: it can generally be divided into two main categories: linear analogue circuits and non-linear analogue circuits. Analogue circuits where the output signal varies linearly with the input signal are often referred to as linear analogue circuits, such as operational amplifiers; audio, IF and wideband amplifiers. I have gained a lot from my visit to the complex medical electronics and have discovered that there are more electronic devices in today's society that need to be upgraded and more invented.

In the future, it is hoped that more sophisticated microstructures with circuit functions consisting of semiconductor wafers will enable existing electronic devices to move towards a future of miniaturization, low power consumption, intelligence and high reliability.

References

[1] Wu Dayong, Ma Qi, Jiang Ping. CMOS analog integrated circuit matching technology and its application [j]. Journal of Hangzhou University of Electronic Science and technology, 2007 (06): 13-16.doi:10.13954/j.cnki.hdu.2007.06.006

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[2] Alan Hastings． The Art of Analog Layout [M] ． Beijing: Electronic Industry Press 2006：511-531．

[3] Behzad Razavi. Translated by Chengjun. Analog CMOS integrated circuit design [M]. Xi'an: Xi'an Jiaotong University Press 2003:376-382

[4] R Baker Harry Li David Boyce． translated by Chen Zhongjian． CMOS Circuit Design． Layout and Simulation [M]. Beijing：Machine Press 2006：100-105．

[5] Robert A Pease．Comments on 'analog layout using ALAS！'[J]. IEEE Solid-State Circuits 1996 31（9）：1364-1365．

[6] Marcel M, Aad J, Aaton G．Matching properties of MOS Transistors [J]. IEEE Solid-State Circuits 1989 24(5): 1433-1440．