Research on the Polygraph: the CMOS Neural Amplifier

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Abstract. The polygraph is an effective piece of equipment to detect if the suspect is lying in order to track down the criminal. The paper simulates and sets up the host part of the polygraph in order to explain how the polygraph works and some fields to use it. And we successfully make a neural amplifier to show the way that the host amplifies neural signals, and has a low passband that can filter out high-frequency signals. The circuit has two parts the folded cascode amplifier DC gain is 64.56, the -3dB bandwidth is about 100kHz and the total current consumption is 4uA and the capacitive feedback amplifier passband gain is 40dB and the passband is from about 3Hz to 5kHz. It is of great value not only in the field of criminal investigation, but also in VR, artificial intelligence (AI), and mental health. Because it can record and let people observe human brain activity and emotional changes. What's more, with its development of it, it can solve many small crimes automatically, which means police can have more time and energy to deal with difficult cases and society can be more stable.

Keywords: polygraph, CMOS neural amplifier

1. Introduction

Today, with the development of technology, there are more and more kinds of technological creations which can help us in many fields. Among these creations, the polygraph is an effective piece of equipment to detect if the suspect is lying in order to track down the criminal.

Polygraph is a scientific instrument used to record the physiological changes of people when their emotions change. In the 1890s, the first lie detector was developed by Ceu are Lombroso and used to solve crimes. It worked by measuring changes in a person's pulse and blood pressure to determine whether a person was lying. Fifty years later, a new generation of lie detectors came out. John Reid laid the foundation for the lie detector, adding measurements of breathing, skin resistance changes, and muscle activity to the original measurement principles. In 1960, technology continued to evolve, and so did polygraphs, which became electronic. In 1981, China introduced an American MarK-arK-981, China introdut, the use of polygraphs gradually became widespread. The research shows that the accuracy of a lie detector is approximately 80%, which has a high reference value.

The paper mainly studies the host part of the polygraph. And the amplify function of it is simulinked and made some improvements. A neural amplifier consists of a folded cascode amplifier and a capacative feedback amplifier is used.

The polygraph is an effective means of criminal investigation, especially in the process of examining evidence. At the same time, it combines psychology, criminology, biology, electronics and computer science, which is a good means to study the aspects of people's mind activities and the working principle of the brain to promote AI and VR technology. What's more, it can also help psychologists to deal with mental problems. While the usage of polygraphs is becoming more and more extensive, it is vital to improve the accuracy, functionality and credibility of polygraphs.

2. The Polygraph

2.1. The operating principle

The polygraph can record physiological changes when the subject is questioned. When liars make up lies, they usually worry about being exposed, so they feel psychological pressure, which is resulted in psychological reactions such as nervousness, fear, anxiety, and guilt. At the same time, there are a

series of physiological reactions controlled by the autonomic nervous system like heart rate, blood pressure, temperature, sweating, muscle contraction, secretion of hormones in the body, etc. Measuring changes in these data and through a series of comparisons can determine whether the offender is lying.



Figure 1. The polygraph

2.2. Measurement index

The historical measurement indexes of polygraph are blood pressure, skin temperature, voice, electroencephalogram, electrocardiogram, pupil, electromyography, adrenaline, etc. At present, the commonest measurement indexes are pulse, respiration and skin resistance.

2.3. The configuration

The polygraph consists of sensors, a host and a microcomputer. Sensors are transistors that connect to a person's body and collect data, which is transmitted to a host in the form of analog signals. The host is a kind of electronic component which can amplify analog signals collected by sensors and convert them into digital signals. And the input digital signals will be stored and analyzed by the microcomputer to get the lie detection results.

3. The Amplifier Design

As the most important equipment among polygraph, the host is a kind of electronic component. Its main function is to amplify analogy signals collected by sensors and convert them into digital signals. The improvement of its performance can improve the accuracy of signal measurement of polygraph and make it easy for the microcomputer to analyse. And this paper mainly focuses on amplification function of the host. And in this paper, capacitive feedback amplifier was choose to realize amplification function.

3.1. Amplifiers classification

Amplifiers are classified into three types: transistor amplifiers, operational amplifiers and functional amplifiers. Operational amplifiers (op-amp) are been mainly used in this paper. They have very high linear gain. They are used to perform mathematical operation such as addition, inversion, integration and so on. Thus it’s called operational. When they are built block of many analogy integrated circuits and systems, they become functional amplifiers. Applications include: sensor front-ends, medical electronics, communications, audio electronics, A/D conversion.

3.2. The operating principle of MOS and amplifier

MOS comes in many varieties, like PMOS, JMOS. Modern CMOS uses polysilicon gates instead of metal gates. The wide use of MOS has an inseparable relationship with its series of characteristics, such as: the characteristics of MOS can change with the change of voltage, at low voltage, it has a cut-off characteristic; At suitable voltage, it has the triode characteristic and at alternating high voltage it has the saturation characteristic.

The operational amplifier is composed of positive and negative two phase input terminals and output terminals, and its main principle is a voltage amplifier to achieve voltage gain. When fed from the positive phase, operational amplifiers form positive feedback circuits that are often used to generate oscillatory signals required by the circuit. The negative feedback circuit formed by negative phase input is more stable.

3.3. Performance index of amplifier

The open-loop voltage is expressed as A_v=U_o/U_i. When the output of the op-amp is not connected to the input, the open-loop voltage gain is defined as the ratio of the output voltage to the input voltage, and its size determines its performance. The greater the gain, the better the performance. The output voltage of the operational amplifier has a maximum amplitude, denoted as U_opp. If the maximum value is exceeded, the distortion will occur. For example, when F007 is in the circuit with a supply voltage of plus or minus 15V, the maximum voltage it can output is 12V. This value is therefore called its maximum undistorted output amplitude at the specified supply voltage. Ordinary operational amplifiers have resistance values inside; The Davinan equivalent resistance seen from the amplifier's output is called the OPamp's output resistance R_0. The output resistance of the ideal amplifier is 0, so to get closer to the ideal amplifier, the output resistance of the OPamp should be as small as possible. In a static circuit, the input DC voltage is not zero; In order to have only AC voltage, a compensating voltage is applied between the two inputs. This compensating voltage is used to make the DC voltage equal to zero. It is also called the input bias voltage. In an ideal op-amp, the value of this parameter should be close to 0, so th input bias voltage of a normal op-amp should be as small as possible. The input bias voltage shows the matching degree of the differential amplifier at this stage. With input bias voltage, there is a corresponding input bias current in the static circuit. The DC currents of the two input channels are respectively expressed as I_B1 and I_B2, and the total input bias current is the average value of the two currents. Similar to the input offset voltage, the input offset current value of an ideal op-amp should be close to 0, and the average op-amp should be as small as possible. The bandwidth when the open-loop voltage gain of the op-amp is reduced to $1/\sqrt{2}$ times the DC gain (-3dB) is called the -3dB open-loop gain bandwidth of the op-amp and is denoted by BW. The bandwidth at which the open-loop voltage gain drops to 1 is called the unit-gain bandwidth and is denoted by BWG. The open-loop gain bandwidth of an ideal op-amp should be infinite.

3.4. Performance index of amplifier

To design a feedback amplifier, an operational amplifier should be designed firstly. There are many kinds of operational amplifiers, such as bipolar operational amplifiers, JFET operational amplifiers and CMOS amplifiers. This paper chooses CMOS amplifiers. Because most popular technology for realizing integrated circuits uses MOS transistors. The reason is that CMOS amplifier has many well-practiced characteristics at low frequency, such as low power consumption, wide working voltage range, strong anti-interference ability. In general, CMOS operational amplifier consists of five parts, which are input stage, intermediate stage, output stage, bias circuit and compensation circuit. The input stage generally uses differential amplifier, differential input, which can have a higher gain and have a better anti-noise performance. Meanwhile, it can make a better common mode rejection. In order to obtain the maximum voltage gain and output swing, the intermediate stage is composed of common source amplifier. The output stage is mainly used for buffer matching with the subsequent circuit, solving impedance matching problems and appropriate

power drive. The bias circuit is designed to provide DC voltage or current for all stages of amplifier circuit, and to guarantee that the MOS can work in the saturation region. The compensation circuit is established to ensure the stability of the gain when the op-amp is working in closed-loop.

Compared with the conventional MOS operational amplifier called the telescopic operational amplifier, the folded cascode amplifier has a much wider range of working voltage and a lower bias voltage. Meanwhile, the input and output can be short-circuited, and the input common-mode level is easier to select. So, the folded cascode amplifier is much more widely used.

And this paper designs a folded cascode amplifier. The circuit diagram is as follows.

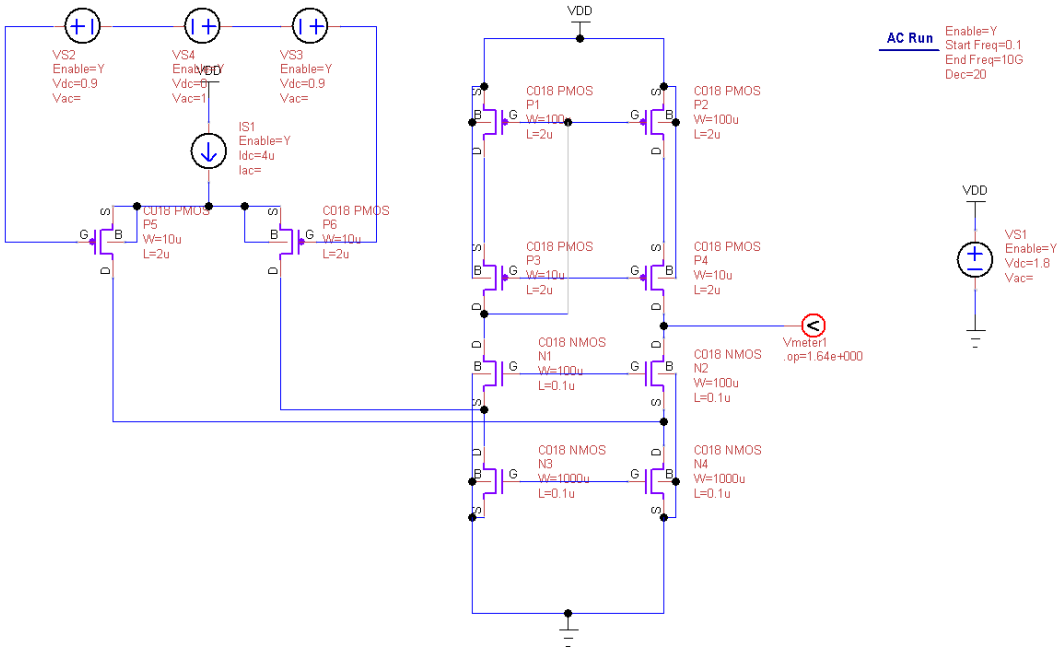


Figure 2. The folded cascode amplifier simulation circuit diagram

4. The Neural Amplifier Design

The neural amplifier is an amplifier that is specifically designed to amplify biopotential signals that arise from the nerves. Such amplifiers require low power, high gain with a bandpass characterises from sub-Hz to a few kHz.

4.1. The operating principle of neural amplifier

The neural amplifier consists of a folded cascode amplifier and a capacitive feedback amplifier. And the feedback amplifier falls into two categories, negative and positive. The Feedback signal and the input signal polarity are opposite or their direction of change are opposite (reverse phase), so the result of superposition will make the net input signal weakened. When the signal is fed from the reverse input node to the amplifier, the output signal is in the opposite phase to the input signal. In contrast, when the signal is fed from the in-phase input node to the amplifier, the output signal and the input signal are in-phase. When two input nodes input signals simultaneously, the operational amplifier performs subtraction operation, and the output signal is in phase with the larger output signal. Operational amplifier is a kind of integrated circuit that can amplify analogy signal well and does not make its distortion, because operational amplifier has very big voltage gain generally, high to tens of thousands of times, so its output end and input end are often connected together to form a negative feedback circuit, thus ensuring the stability of the inner ring. However, some operational amplifiers form positive feedback circuits to provide oscillatory signals.

4.2. The neural amplifier design

To design a neural amplifier, there should be a amplifier. So, the paper chooses the folded cascode amplifier and its design and simulation are explained in the third part. And it also consist of a feedback circuit. Among many kinds of feedback circuit, the paper chooses the capacitive feedback amplifier. The reason is that the capacitive feedback amplifier can easily change the passband and improve circuit stability, and the impedance can increase as the frequency increases so that it has strong resistance to high frequency noise at the same time. Among the indicators of the lie detector, whether it is the neural signal or the heartbeat, they are low-frequency signals, so the capacitive feedback amplifier is a good choice. And this paper designs a capacitive feedback amplifier. The circuit diagram is as follows.

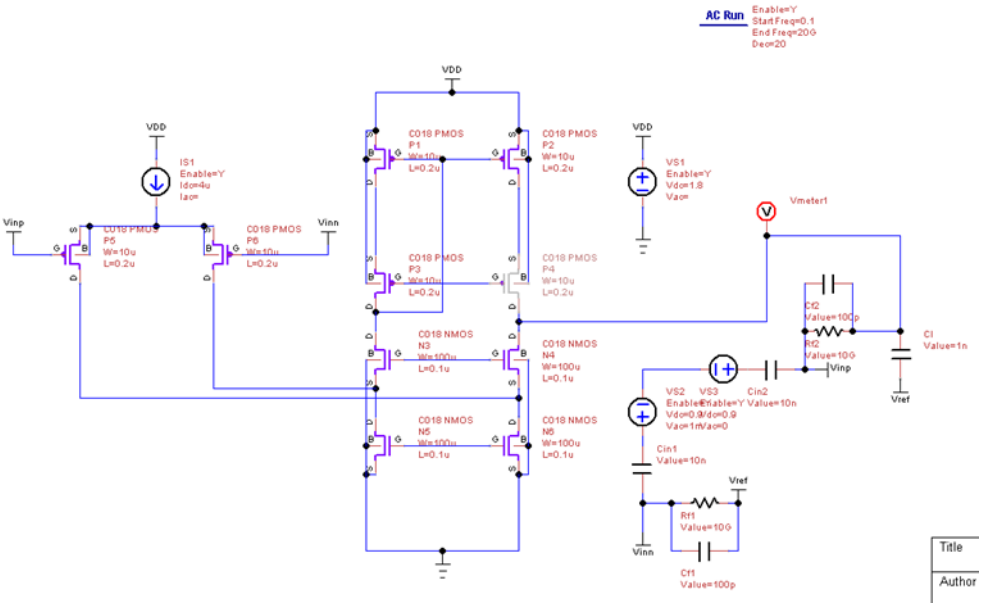


Figure 3. The capacitive feedback amplifier simultion circuit diagram

5. Simulation and Analysis

The paper uses Coolspice to simulate the circuit. In the simulation circuit, the left side of the circuit is a current mirro consisted of two PMOS in order to provide a bias current. In the middle of the circuit, it is a cascode ampifier. And combining with the circuit in the right side, it comes to a capacitive feedback amplifier. C_f can reduce the gain of high frequency and R_f can limit amplification so that the mos can work in saturation region. The gain is C_in divide C_f. C_l can make the circuit stabler. The passband can be changed via tuning C_l and C_f. As a result, the waveforms are shown via the plotter function in the coolspice. The simulation results are shown below.

Table 1. The parameter of the folded cascode amplifier in the DC state

V_{in}	V_{out}	V_{DD}	I_{in}	I
1mV	1.69V	1.8V	4uA	1.99uA

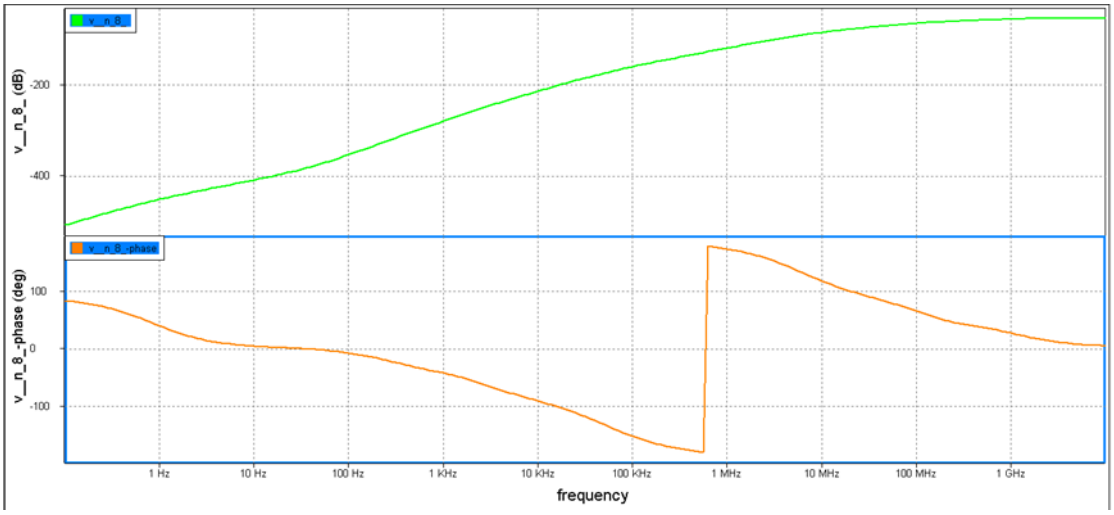


Figure 4. The output signal varies with frequency in the folded cascode amplifier

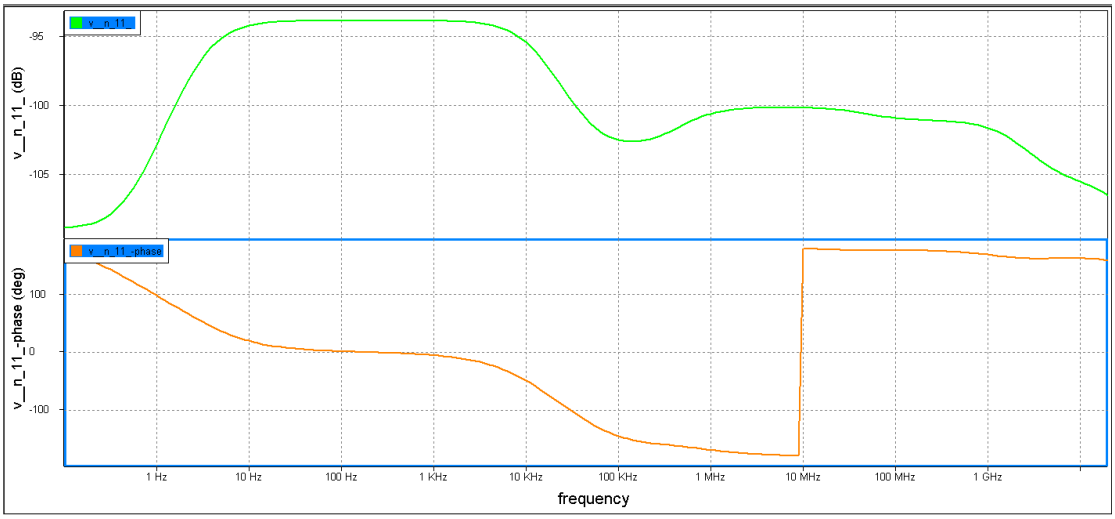


Figure 5. The output signal varies with frequency in the capacitive feedback amplifier

In the figure, the green line shows the magnitude of the output voltage (20 logf_0 〖V_0=〗 v_n_11_(dB)) and the orange line shows the phase of the output voltage

Form the simulation, The circuit has the following parameters:

The folded cascode amplifier DC gain is 64.56, the -3dB bandwidth is about 100kHz and the total current consumption is 4uA.

The capacitive feedback amplifier passband gain is 40dB and the passband is from about 3Hz to 5kHz.

6. Challenges and Improvements

Although the folded cascode amplifier has a much wider range of working voltage, a lower bias voltage and other advantages, it comes at the cost of increased power consumption and reduced gain. Meanwhile, the cmos operational amplifier is easily influenced by the temperature and the high voltage. And from a price point of view, its workmanship is complex and the price is high. So it also needs to make some improvements to the electronic component.

For the polygraph, it has certain limitations. A majority of people believe that the lie detector may fail because of the serious psychological problems. Criminals can be able to lie calmly to the lie detector, because some of them may feel that the "torture" of the victims is natural and deserved. However, there are some people who believe that lie detectors have no effect on the people who have calm minds or are well trained. In addition to the accuracy of the machine, the accuracy of the lie detector also depends on many other aspects, such as the intelligence of the subject, mental state,

health level, test environment, test conditions, etc. What's more, tests have shown that the professional level of lie detector personnel is also closely related to this. What's more, polygraph tests can also be biased and wrong for people with mental illness, congenital heart disease, or sinus arrhythmia. But it still has a relatively high reference value. At the Public Security University test center, after more than 1,000 criminal cases, the suspect exclusion rate is 100 percent and the identification rate is more than 80 percent.

7. Conclusion

In conclusion, the simulation successfully shows the circuit structure, its working operation and its parameters. The amplifier consists two parts: the folded cascode amplifier and the capacative feedback amplifier which its gain is controled by C_in and C_f. In terms of paramters, the folded cascode amplifier DC gain is 64.56, the -3dB bandwidth is about 100kHz and the total current consumption is 4uA, while the capacitive feedback amplifier passband gain is 40dB and the passband is from about 3Hz to 5kHz. The amplifier has a great low-pass effective and a high gain which can amplify the neural signal nicely. However, it also needs some improvement, such as a greater magnification, a less power consumption and a greater temperature resistance. To deal with these problems, the current mirror that generates the bias current can be modified. At the same time, MOS can be improved to reduce the influence of temperature With the development of amplifier, it will become easier and easier to catch the criminals and obtain precise evidence in the field of criminal investigation. Meanwhile, it could also promote artificial intelligence, VR, mental health care and a host of other brain-related technologies.

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