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# Design and Testing of a Fast-Response Preamplifier

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**Abstract:** This article presents the design of a high-speed, low-noise preamplifier specifically intended for amplifying high-frequency weak electrical signals. Firstly, a thorough analysis was conducted on common types of preamplifiers, and it was proposed to adopt a charge-sensitive preamplifier as a solution for signal output amplification. Subsequently, a specific circuit was carefully designed and thoroughly analyzed to ensure it meets the strict requirements of low noise and nanosecond-level response. To verify the feasibility of the designed amplification circuit, an actual circuit board was fabricated and electronic tests were conducted. The test results revealed that the electronic noise of the amplifier was only 5mV, and the signal response time was within 5ns, fully demonstrating its excellent performance.

**Keywords:** Preamplifier, Quick Response, Low Noise.

## 1. Introduction

With the rapid development of science and technology, the acquisition and analysis of weak signals play an increasingly important role in various fields such as communication, biomedicine, and physical detection [1-3]. These weak signals often carry crucial information, but their small amplitude and high frequency make their acquisition and analysis particularly challenging. As the starting point of signal acquisition, sensors often require amplification of their output electrical signals to improve measurement accuracy and signal-to-noise ratio. Therefore, as a crucial component in the signal acquisition system, the performance of the preamplifier directly affects the performance of the entire system. The main task of the preamplifier is to amplify the weak signals output by the sensor for further processing by subsequent circuits. However, due to the inherent characteristics of weak signals, the design of preamplifiers faces numerous challenges. On one hand, it is necessary to ensure that the amplifier has a sufficiently high gain to amplify the weak signals to a manageable level. On the other hand, it is also crucial to minimize noise interference to ensure a high signal-to-noise ratio after amplification [4,5]. Additionally, for high-frequency weak electrical signals, the preamplifier must possess the capability of quick response to accurately capture the dynamic changes of the signals [6,7]. Addressing these issues, this article aims to design a high-speed, low-noise preamplifier specifically intended for amplifying high-frequency weak electrical signals. Test results demonstrate that the amplifier exhibits excellent performance, with an electronic noise of only 5mV and a signal response time within 5ns, meeting the design requirements. The high-speed, low-noise preamplifier designed in this article not only provides an effective solution for the acquisition and analysis of high-frequency weak electrical signals but also offers a useful reference for research and applications in related fields.

## 2. Design and Analysis of the Preamplifier Circuit

### 2.1. Selection of Preamplifier Type

Preamplifiers are categorized into integral types and current types. The integral types are further classified into voltage-sensitive preamplifiers and charge-sensitive preamplifiers. The output amplitude of the integral types is proportional to the integral of the input current over time, which is equivalent to being proportional to the charge output by the sensor. In contrast, the current-type preamplifiers produce output signals that are consistent with the current waveform output by the sensor [8-10].

The operational mechanism of the voltage-sensitive preamplifier is detailed in Figure 1. It utilizes a specific capacitive integration mechanism and signal amplification process to enhance and process the output signal. The sensor outputs a current signal to the preamplifier, with a duration of $t_w$ and an amplitude of I. The total charge Q is obtained through the integration of current over time, i.e., $Q = \int_0^{t_w} I dt$. When $t_r$ is much smaller than $t_w$, Q can be approximated as $It_w$. The current signal is integrated on $C_{in}$, converting it into a voltage $V_{in}$, where $V_{in}$ is proportional to Q. $V_{in}$ is then amplified by the amplifier to obtain $V_{out}$. $C_{in}$ is composed of multiple unstable capacitors, including the output capacitor $C_d$, distributed capacitance $C_p$, and the input capacitance $C_a$ of the amplifier itself. The coupling capacitor $C_d$ can vary with changes in the P-N junction voltage, while the input capacitance $C_p$ is affected by the length of the connecting cable. Additionally, the output capacitance $C_a$ can also vary with changes in the amplifier's gain. Connecting a large parallel capacitor can reduce the influence of unstable factors, but it can also lead to a decrease in signal-to-noise ratio. Voltage-sensitive amplifiers have limitations in high-resolution energy spectrum measurements but can be valuable in time measurements.

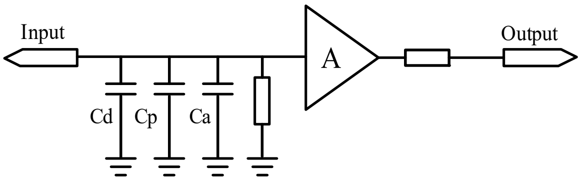

**Figure 1.** Schematic Diagram of a Voltage-Sensitive Amplifier

The operational amplifier in the charge-sensitive preamplifier is connected across a capacitor $C_f$, and the output signal amplitude is approximately equal to the voltage on $C_f$. Since $C_f$ is a constant, the output voltage is only related to the total charge, resulting in good stability. Therefore, it can be used as a high-energy-resolution spectroscopy measurement system. The principle is illustrated in Figure 2.

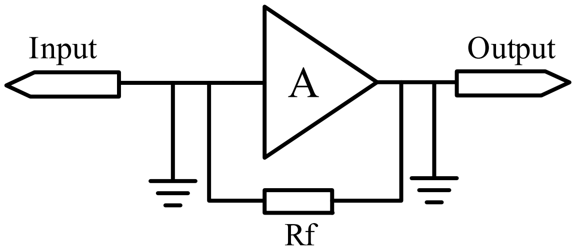

**Figure 2.** Schematic Diagram of a Charge-Sensitive Amplifier

The current-sensitive preamplifier directly amplifies the detector's current signal without the need for capacitive integration. Its output is directly proportional to the input current, and its working principle is illustrated in Figure 3. The current-sensitive preamplifier is a parallel resistance negative feedback current amplifier, with an output $V_{out}$ equal to $IR_f$. Its characteristics include fast response, accurate acquisition of timing information, matching impedance with high-frequency cables to enable long-distance transmission; short pulse rise time, narrow pulse width, and stable operation at high counting rates. However, it also exhibits high bandwidth and increased noise.

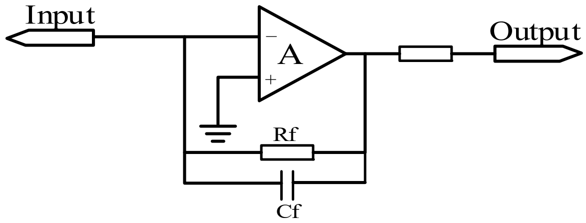

**Figure 3.** Schematic Diagram of a Current-Sensitive Amplifier

## 2.2. Circuit Design

This time, a new preamplifier was designed using LMH6629 as the core in a two-stage cascade configuration, as shown in Figure 4. LMH6629 is a high-speed, ultra-low noise amplifier suitable for applications requiring broadband, high gain, and low noise. It operates with a supply voltage ranging from 2.7 V to 5.5 V and can swing its output within 0.8 V of the power rail, making it ideal for single-supply applications. With low input noise, low distortion, and ultra-low DC error, it is suitable for both AC and DC coupling applications. The experimental results showed that the best performance of this preamplifier was achieved when the feedback capacitors in both the front and rear stages were left empty. This is because the noise of this amplifier is relatively low, and the pre-voltage generated by the signal current passing through the grounding resistor R21 acts directly on the positive input of the amplifier. Through the first-stage circuit, the current signal output by the detector is converted into a voltage signal, and after the secondary gain of the second stage, the output signal-to-noise ratio and signal gain of the preamplifier both meet the required amplification requirements. If feedback capacitors are added, the time constant RC would increase the rise time, causing overlap between different small signals. Therefore, no feedback capacitors are used in this preamplifier.

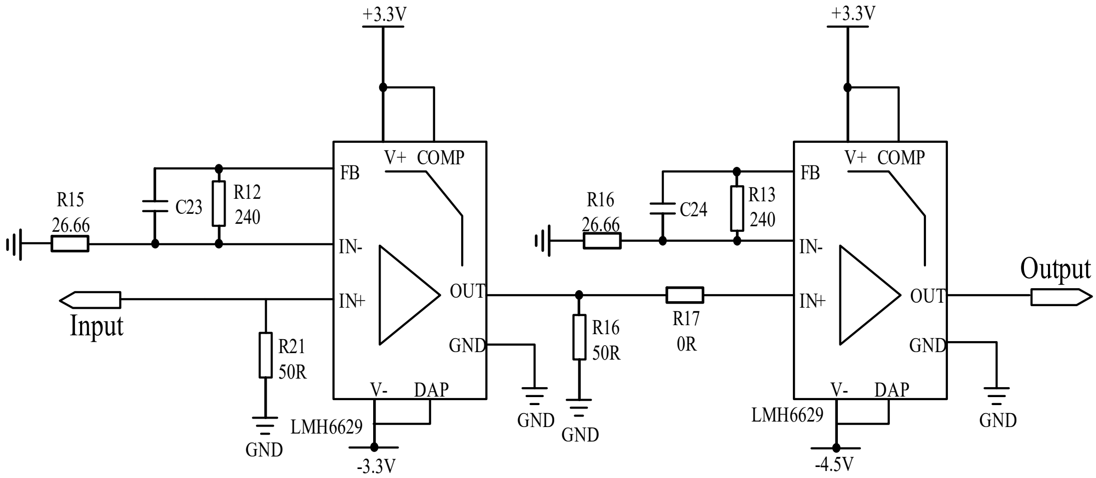

**Figure 4.** Circuit Design Diagram

## 2.3. Noise Testing

During the signal acquisition process, random noise can interfere with useful signals, thereby affecting the accuracy of measurements. Although some noise can be suppressed through experimental means, some noise originates from the electronic devices themselves and is difficult to completely avoid. Therefore, selecting low-noise devices is crucial. To investigate the electronic noise performance of this preamplifier, both the input and output of the amplifier were connected using 50-ohm impedance-matched wires. Its output was connected to a RIGOL HDO4404 oscilloscope through an SMA coaxial cable, and the measured electronic noise is shown in Figure 5. Through noise testing, it can be seen that the noise floor ranges from 5mV, which is a relatively low level. For applications requiring high precision and low noise, it is ideal during measurement or signal processing.

**Figure 5.** Electronic Noise Test Diagram

## 3. Test Analysis

To thoroughly investigate the performance of the preamplifier in practical applications, this article specifically conducted an analysis experiment on the signal rise time. The overall experimental process is shown in Figure 6. First, a strontium source was used as the signal source. Subsequently, the signal generated by the strontium source was converted into an electrical signal through a sensor. Then, this weak electrical signal was amplified by the preamplifier. After that, a sampling module with a sampling rate of 1GS/s was used to collect data from the amplified signal. Finally, the collected data was stored on the host computer for subsequent analysis and processing. Through this comprehensive experimental process, it is possible to more accurately evaluate the performance of the preamplifier in practical applications.

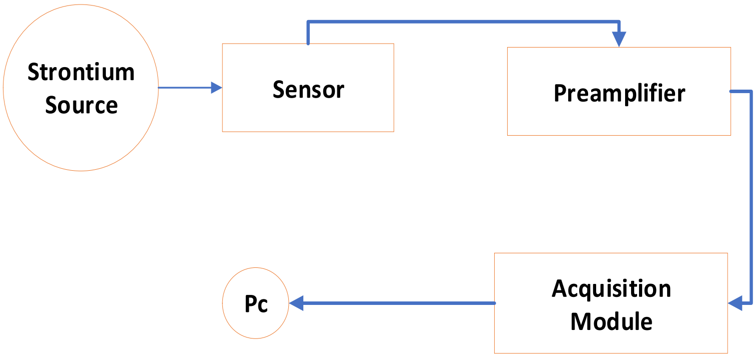

**Figure 6.** Schematic Diagram of the Experimental Process

The signal rise time, as a key performance indicator of the preamplifier, directly reflects its reaction speed and response capability to rapidly changing signals. It not only reveals the bandwidth characteristics of the amplifier, but is also closely related to the degree of distortion. Generally speaking, an increase in bandwidth is often accompanied by a shorter rise time, which in turn reduces the interference from distortion and noise.

To accurately analyze the rise time of the experimental data, the time difference between the local maximum point and the nearest inflection point was adopted as the metric for measuring the rise time. In this process, the local maximum point was determined by the zero point where the first-order derivative changes from negative to positive, while the inflection point was identified based on the zero point where the second-order derivative changes from positive to negative. As shown in Figure 7, the blue points mark the positions of the inflection points, and the green points indicate the positions of the zero points. This method improves the accuracy of the rise time measurement because it fully considers the local features of the waveform, rather than relying solely on numerical values at a single time point. Through this approach, we successfully determined the starting and ending points of the rise time, allowing for a more precise calculation of the rise time. As shown in Figure 8, the experimental data indicates an average rise time of 3.631 ns. This fast rise time means that the preamplifier can quickly respond to changes in the input signal, enabling high-frequency response.

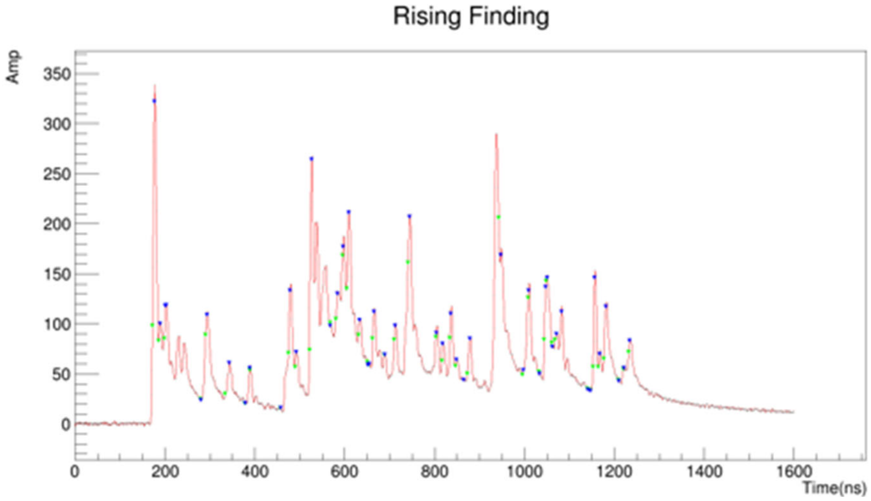

**Figure 7.** Example Diagram of Rise Time

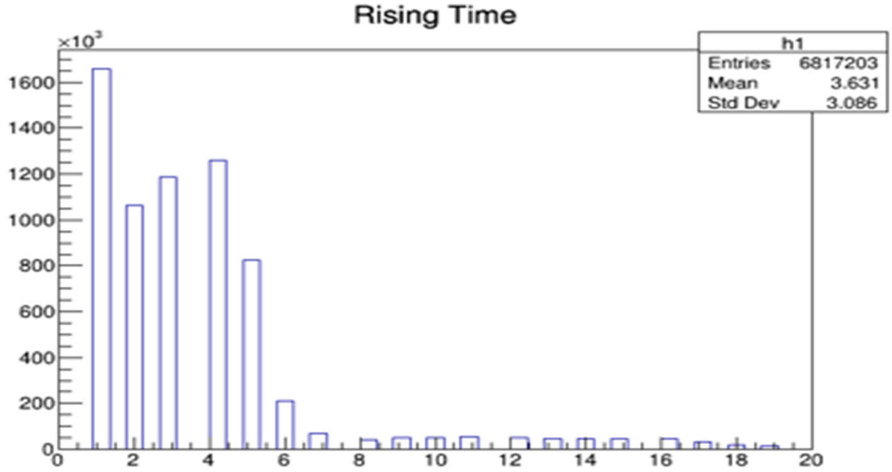

**Figure 8.** Statistics of Rise Time

# 4. Conclusion

This study proposes a two-stage cascaded preamplifier circuit based on the LMH6629 chip, which is particularly suitable for applications requiring wide bandwidth, high gain, and low noise. After testing, it was found that the circuit's inherent noise remains at a relatively low level of 5 mV, making it an ideal choice for high-precision and low-noise requirements in measurement or signal processing processes. Furthermore, through a detailed analysis of the signal rise time, it was discovered that the average rise time is 3.631 ns, which fully meets the design expectations. This result demonstrates that the system exhibits excellent performance in signal transmission and response, possesses high stability and performance advantages, and can fully meet the design requirements. Based on these analysis results, further optimization of the system can be carried out to adapt to more diverse and complex working environments and demands.

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