Application of High Resistance Operational Amplifier CA3140A in Signal Conditioning Circuit of Gamma Logging Tool

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Abstract—The current type signal of gamma detector in gamma logging tool is generally weak, which can not be directly input into microcontroller for pulse counting and statistical analysis. The signal conditioning circuit is designed by using high performance, low noise, small volume single operational amplifier CA3140A, which processes the weak signal from gamma detector, and realizes the corresponding hardware circuit according to the actual application requirements. The experimental results show that: the circuit design performance is stable, and can effectively pick up and process the effective pulse signal, which meets the expected design requirements.

1. Introduction
As a necessary curve in the process of oil and gas exploration and development, Natural gamma ray logging curve is also the most basic and important curve, which is of great significance for lithology division. Rocks contain natural radionuclides, which emit gamma rays spontaneously during natural decay. When the natural gamma ray logging tool receives these rays, it will convert them into electric pulses, and the number of electric pulses is directly proportional to the intensity of gamma rays. The number of electric pulses per unit time is calculated by gamma ray logging tool, so as to obtain the lithology of measured rock [1-3]. The pulse signal that reflects the formation radioactive intensity information output by the gamma detector of logging tool is considered to be extremely weak [4-6]. Therefore, it is necessary to pick up and amplify the signal before conditioning and counting by the subsequent processing circuit. However, the noise signal caused by the thermal noise of the components and the dark current of the photomultiplier tube often submerge the effective signal. Therefore, the interference of noise on the effective signal should be eliminated as far as possible to improve the signal-to-noise ratio [7-8].

This paper introduces the signal conditioning circuit of gamma logging tool based on CA3140A high integrated operational amplifier with high input impedance, low output impedance and low noise. The design circuit is verified in the laboratory and meets the expected design requirements.

2. CA3140A Performance Parameters
In the design of signal conditioning circuit for gamma logging tool, a high input impedance and ultra-low output impedance operational amplifier CA3140A developed by American radio company is selected. Its internal block diagram is shown in Figure 1. The chip is a low-noise monolithic operational amplifier which integrates the advantages of high-voltage P-MOS and Bipolar technology. It has a wide range of operating power supply voltage from 4V to 36V, input impedance up to 1.5 TΩ, and output...
impedance as low as dozens of ohms. The maximum open-loop gain can reach mega-level, and the input bias current is about 0.5 PA when the operating voltage is ± 15 V When the bias voltage is 5 mV, the maximum power consumption is less than 200m W [9].

3. Composition of Signal Conditioning Circuit
The signal conditioning circuit of gamma logging tool is mainly composed of signal pickup and amplification circuit, signal identification circuit and pulse shaping circuit. The circuit structure diagram is shown in Figure 2.

4. Circuit Design and Test
The formation gamma ray intensity information output by gamma detector in gamma logging tool is a weak negative current signal, and the signal is often mixed with various kinds of noise, and only the pure, reaching a certain amplitude, positive signal can be received and counted by the microcontroller. Therefore, it is necessary to design a signal conditioning circuit to standardize the non-standard signal.

4.1. Signal Acquisition and Amplification
Due to the weak output current signal of photomultiplier tube anode, the operational amplifier should have high open-loop gain and high input impedance when picking up and amplifying the signal. At the same time, the output impedance of the selected operational amplifier should be as small as possible to reduce the influence of voltage drop on the output voltage. In the case of small internal resistance, the operational amplifier can be approximately regarded as a voltage source, so that the output voltage will not change with the lower load. In addition, the selected operational amplifier should also meet the requirements of low input bias and low noise.

In the signal conditioning circuit of gamma logging tool, the signal pick-up and amplification circuit are used to transform the weak and negative current signal from the anode of photomultiplier tube in gamma detector into voltage signal, which is further processed by the subsequent signal conditioning circuit. In the design of the circuit, CA3140A operational amplifier developed by Radio Corporation of America is selected.
The signal pick-up and amplification circuit of gamma logging tool is composed of two-stage CA3140A operational amplifier. The first stage of operational amplifier can pick up the weak current signal output by gamma detector, convert it into positive voltage signal, and realize in-phase amplification of signal by the second stage operational amplifier. The principle of signal pickup and amplification circuit is shown in Figure 3.

Figure 3 Schematic diagram of signal picking and amplifying circuit

The output signal \( I_A \) of the gamma detector is fed into the reverse phase input of the first stage operational amplifier after the coupling capacitance \( C \) is isolated. The feedback resistance \( R_F \) is bridged between the reverse input end and the output end of the operational amplifier, and the in-phase input end of the operational amplifier is grounded. In this way, the output voltage of the operational amplifier is the same as the voltage at both ends of the feedback resistor, and the calculation formula is shown in (1):

\[
V_{01} = -I_A R_F
\]

Where \( V_{01} \) is the output voltage, unit: V; \( I_A \) is the output current of gamma detector, unit: A; \( R_F \) is the feedback resistance, unit: \( \Omega \).

For the photomultiplier tube in gamma detector to work normally, it is necessary to provide appropriate DC bias voltage for each multiplier pole by peripheral circuit. However, in order to reduce the additional noise caused by the partial voltage bias circuit, the high voltage bias circuit with positive high voltage connection is adopted in the design, that is, the anode is connected to the positive pole of the high voltage power supply, and the cathode is connected to the low potential. At the same time, in order to ensure that the high voltage of the high voltage bias circuit does not affect the signal conditioning circuit, the direct coupling capacitor \( C \) used in the circuit selects the ceramic dielectric capacitor with the withstand voltage value no less than 1500V, small leakage current and good frequency characteristics.

In the actual circuit design, in order to solve the problem of signal phase lag caused by input capacitance, coupling capacitance at load end and bypass capacitance caused by input signal and circuit oscillation, feedback capacitor \( C_F \) is paralleled at both ends of feedback resistance \( R_F \) to eliminate oscillation, and feedback capacitor \( C_F \) can also suppress noise.

4.2. Signal Identification Circuit

The negative pulse signal output by the gamma detector includes not only the information reflecting the radioactive intensity of the formation, but also the noise pulse signal caused by the dark current of the multiplier tube itself, the external cosmic rays, and the thermal noise of circuit components. As shown in Figure 4, these noise signals will have a certain impact on the pulse counting accuracy of the gamma logging tool. Therefore, the ratio of the identification circuit composed of comparator and threshold voltage circuit is shown in Figure 5 to eliminate noise pulse signal and retain effective pulse signal.
In the circuit, $V_{O2}$ is the output signal of signal pick-up and amplification circuit, which will be used as the input signal for signal identification; $V_{ref}$ is the threshold voltage of identification circuit, and its value depends on the maximum value of dark current pulse and thermal noise pulse of photomultiplier tube used in gamma detector. Thus, the cosmic ray pulse can be ignored. One of the methods to set the threshold voltage $V_{ref}$ of the identification circuit is to observe the amplitude level of the low-end noise at the $V_{O2}$ output end of the signal conditioning circuit with an oscilloscope. Generally, the threshold voltage $V_{ref}$ can be set slightly higher than this value. When the pulse input is zero, the output is low when the input voltage of the comparator is lower than the threshold voltage $V_{ref}$; when the input is an effective pulse signal, the input voltage of the comparator is higher than the threshold voltage $V_{ref}$. After screening by the identification circuit, the effective pulse signal is sent to the pulse shaping circuit.

4.3. Pulse Shaping Circuit

After the pulse identification circuit screening, the effective pulse signal carrying the formation radioactive intensity information is basically square wave signal. The back-end microcontroller can judge the rising edge and falling edge, so as to realize the pulse counting. However, in order to achieve higher counting accuracy and stronger anti-interference ability, the pulse shaping circuit is designed. Natural gamma ray logging is a statistic of the number of pulses reflected by different lithology and different radioactive intensity. Therefore, in order to reduce circuit power consumption, simplify circuit design and improve reliability, a two non-gate circuit is used to realize pulse shaping circuit. The pulse input IO port of the microcontroller is compatible with 5V input. Therefore, the power supply of pulse shaping circuit and identification circuit also adopts 5V power supply.

4.4. Test of Signal Conditioning Circuit

The signal conditioning circuit is tested under laboratory conditions. The signal input is provided by gamma detector, and the required bias voltage is provided for each pole of photomultiplier tube by special DC high voltage power module. According to the photomultiplier tube and signal conditioning circuit used in the test, the plateau characteristic curve and the plateau area range are measured [10]. The output signal of gamma detector is observed with oscilloscope, and the resistance value of feedback resistance $RF$ is adjusted to ensure that the output waveform of the first stage operational amplifier of the signal pickup and amplification circuit is not distorted; the amplitude of the output pulse signal of the second stage operational amplifier in the signal pickup and amplification circuit is observed, and the effective signal can pass through the identification circuit composed of the comparator, thus causing noise. The pulse signal cannot pass through, and the signal waveform is shown in Figure 6. If there is
any inappropriate resistance value of R3, the resistance value can be adjusted until it reaches the expected requirements. The standard pulse signal after the conditioning signal transformation is shown in Figure 7.

![Image](image-url)

**Figure 6** Output signal waveform of signal pickup and amplification circuit

![Image](image-url)

**Figure 7** Output signal waveform after signal conditioning circuit

### 5. Conclude

According to the above design theory and actual circuit realization and test verification, the signal conditioning circuit of gamma logging tool based on high resistance operational amplifier CA3140A is as follows:

1) The signal conditioning circuit of gamma logging tool is designed with CA3140A operational amplifier. The test results show that the circuit has stable performance and can effectively pick up and process the effective pulse signal;

2) The signal conditioning circuit of gamma logging tool based on CA3140A operational amplifier is simple in design, reliable in performance, small in size and low in power consumption, which meets the application requirements of gamma logging tool based on battery power supply and small aperture application;

3) There are many ways to realize the signal conditioning circuit of gamma logging tool. The signal conditioning circuit based on CA3140A operational amplifier introduced in this paper is only one of them. The performance of the circuit still needs to be further tested in practical application, and the optimization design of the circuit also needs to be further optimized in practice.

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