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Design of a New Wide Range Weak Current Measuring System

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Abstract

The measurement of weak current is an important subject of contemporary electronic technology. In order to meet the needs of wide-range weak current measurement, this paper designs a wide-range weak current measurement system based on the method of current-frequency conversion. Measurement. The system has a wide range without switching any device, and the difference between the maximum and minimum values of the measurement range can be 6 orders of magnitude, which can avoid the loss of measurement data caused by switching gears and the influence on the linearity of the system. The system designed in this paper realizes the weak current measurement from -10pA to -10μA, and the experimental verification and measurement data show that it has good accuracy and linearity.

Keywords

Current Frequency Conversion; Weak Current; Wide Range; Negative Current.

1. Introduction

With the rapid development of electronic technology, the research on the measurement of weak electrical signals has become more and more in-depth, and the measurement of weak current has a very important application in all walks of life. There are three main types of measurement methods for weak current, the first is the current-voltage conversion method, the second is the feedback integration method, and the third is the current-frequency conversion method[1-2]. They have various characteristics. For the current-voltage conversion method, it uses transimpedance amplification, amplifies the weak current into a larger voltage, and then collects the measured weak current through the ADC[3]. The response time of this method is short, and it can be quickly measured. For the feedback integration method, it obtains the measured weak current by converting the measured current into the length of the integration time through the integrating circuit[4]. This method has a longer response time but higher measurement accuracy[5].

The current-frequency conversion method is to convert the measured current into pulse signals of different frequencies through the integration circuit and the comparison circuit to realize the weak current measurement. The response time of this method is moderate and the measurement range is relatively wide. In this paper, based on the STM32 microprocessor and using the current-frequency conversion method, a wide-range weak current measurement system is designed.

2. The Principle of the Circuit

2.1 Introduction to the System

The weak current measurement designed in this paper adopts the method of current frequency conversion, which is mainly used to detect negative weak current. The block diagram of the whole system is shown in Figure 1. The measured weak current first outputs the integrated voltage through an integrating circuit, and then passes through a comparator. Monostable multivibrator to generate pulse signal and discharge the integrating circuit. The pulse signal generated by the monostable

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multivibrator obtains its frequency by the timer function of the STM32 microprocessor, and finally obtains the measured value[6-7].

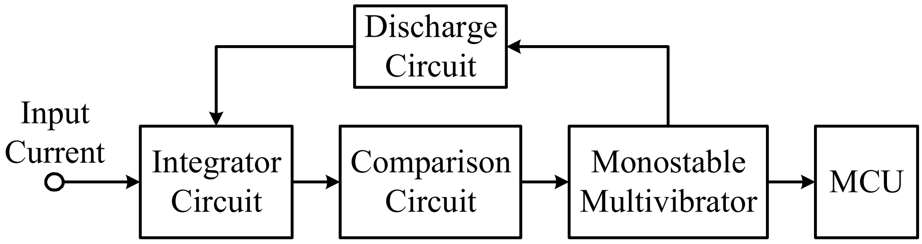

Figure 1. System Block Diagram

The PCB simulation diagram of the whole system is shown in Figure 2. The digital circuit and the analog circuit are divided into blocks to improve the anti-interference ability. The final measurement data is sent to the computer through the serial port function of the microprocessor, and the measurement value is displayed to complete the measurement.

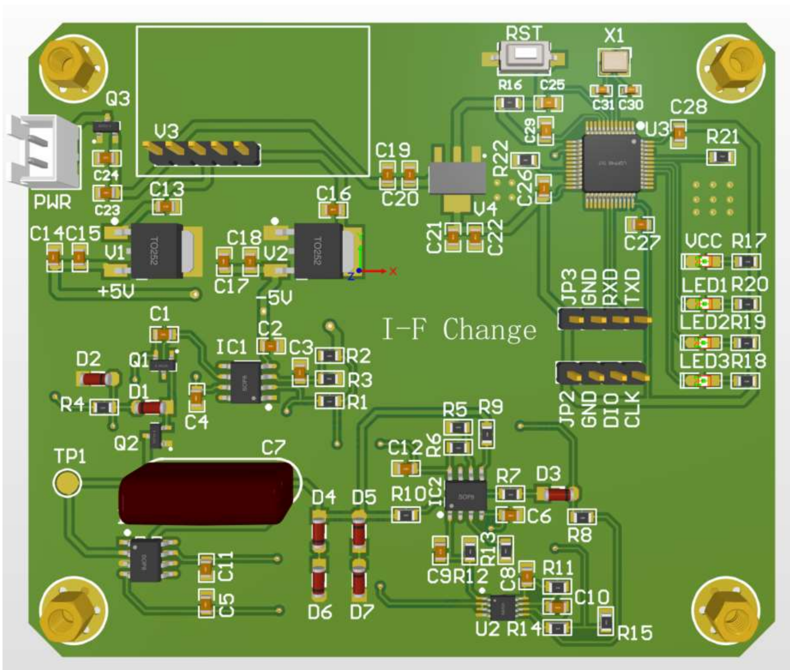

Figure 2. Simulation Diagram of PCB

2.2 Measuring Circuit

The circuit diagram of the measurement system is shown in Figure 3. After the input circuit passes through the integrating circuit, the capacitor C1 begins to store charges. When the voltage of the capacitor C1 reaches the input reference voltage V1 of the comparator U2, the output voltage of the comparator changes from positive to positive. Going negative produces a falling edge that causes the monostable to output a pulse.

The duty cycle of the pulse signal is related to the values of the external resistor R4 and the external capacitor C2 of the monostable multivibrator. According to the characteristics of the operational amplifier, we can get:

$$I = C\frac{d(0-U)}{dt} \tag{1}$$

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According to formula (1), it is assumed that the voltage of capacitor C1 reaches V1 after the time T has elapsed, and we can obtain:

$$\int_0^T Idt = -\int_0^{V1} CdU \quad (2)$$

$$\overline{I}T = -CV_1 \quad (3)$$

$$\overline{I} = -CV_1 f \quad (4)$$

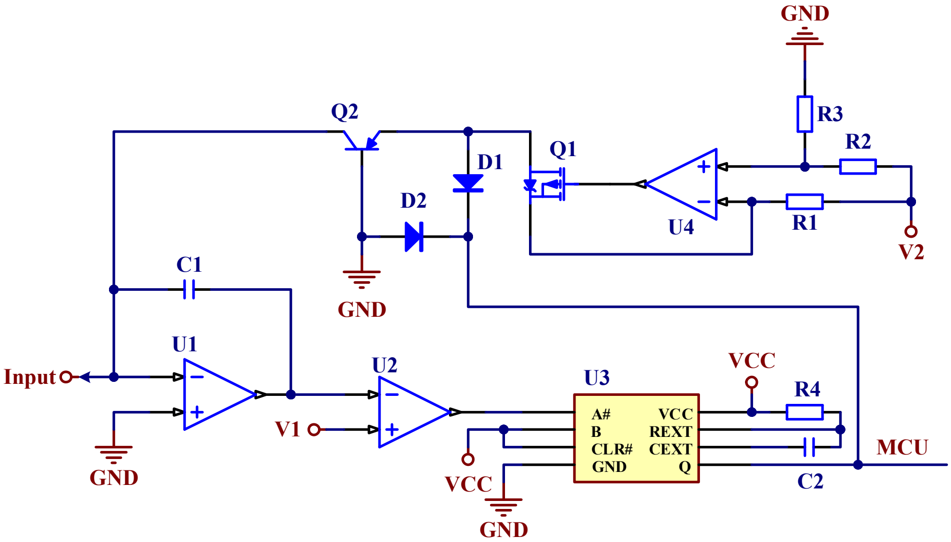

Figure 3. Schematic of The Circuit

In formula (4), f is the frequency of the output pulse signal of the monostable multivibrator. In the case of ignoring the time required for discharge, the average value of the measured current is proportional to the frequency of the pulse signal. However, using the current source built by the MOS transistor Q1, it takes a certain time to discharge the capacitor C1 when the output of the monostable multivibrator is at a high level, and the duration is set to ΔT, that is $f = \frac{1}{T + \Delta T}$, the formula (3) can be modified to have to:

$$\overline{I} = -CV_1 \cdot \frac{f}{1 + \Delta T f} \quad (5)$$

ΔT in formula (5) is determined by the external resistance and capacitance of the monostable multivibrator, and ΔT can be calculated. Then the capacitance C, the reference voltage V1 and the discharge time ΔT are all known quantities, and the average value of the measured current can be calculated only by obtaining the frequency of the output pulse signal of the monostable multivibrator through a microcontroller.

Select the capacitor as 47pF and the reference voltage as 0.2V, then $\overline{I} \approx -9.4f$ (pA). Using the microprocessor to detect the pulse signal from 1Hz to 1000kHz, the range corresponding to the

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measured current is 9.4pA to 9.4μA, which can theoretically achieve a wide range measurement spanning 6 orders of magnitude.

2.3 Discharge Circuit

The discharge circuit is actually a current source circuit composed of an operational amplifier and a MOSFET. The output of the monostable multivibrator is connected to the drain of the MOSFET to control whether the MOSFET is turned on. Therefore, when the output of the monostable multivibrator is high, the MOSFET is turned on, and the current source will discharge the capacitor in the integrating circuit. When the output of the monostable multivibrator is low, the MOSFET is turned off, and the discharge of the integral capacitor is ended[8-9]. The discharge circuit part is shown in Figure 4. For the node of the inverting input terminal of the operational amplifier, according to Kirchhoff's law, it can be obtained:

$$\frac{V_2 - V_{IO} - V_R}{R_1} = I_S + I_{b1} \tag{6}$$

Among them, V_{IO} is the input offset voltage of the operational amplifier, I_S is the source current of the MOS transistor, and I_{b1} is the offset current of the inverting input terminal of the operational amplifier. Then according to Kirchhoff's law, we can get:

$$\frac{V_2 - V_R}{R2} = \frac{V_R}{R_3} + I_{b2} \tag{7}$$

The input offset current of the operational amplifier, $I_{IO} = I_{b2} - I_{b1}$, and for the convenience of circuit design and calculation, make the resistance $R_1 = R_2 = R_3$ can be obtained by combining formulas (6) and (7):

$$I_S = \frac{\frac{1}{2}V_2 - V_{IO}}{R_1} + I_{IO} \tag{8}$$

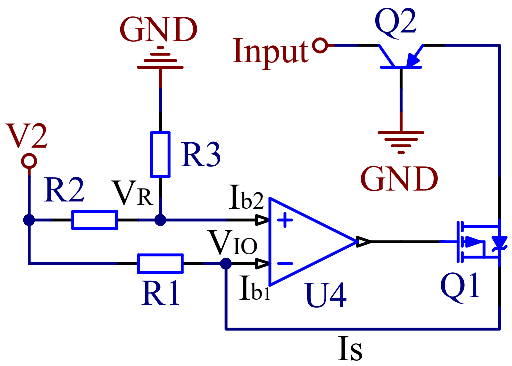

Figure 4. Discharge Circuit

The operational amplifier of the amplifier circuit is OP07C, and the typical values of input offset voltage and input offset current at 25°C are 60μV and 0.8nA, respectively. The input voltage V2 is set to 5V, $R_1 = R_2 = R_3 = 120k\Omega$, then the source current of the MOSFET, $I_S \approx 20.8\mu A$. The source current of the MOSFET limits the maximum value of the measured current. If the measured current

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is greater than the discharge current, the integrating capacitor cannot be discharged, and the voltage of the capacitor will remain unchanged after reaching saturation, so that the monostable multivibrator cannot generate a pulse signal. The integral capacitor designed by the system is 47pF, the reference voltage of the comparator is 0.2V, and the discharge current is about 20.8μA. According to formula (3), it takes about 500ns to complete the discharge. Therefore, the value of the external resistance and capacitance of a set of monostable multivibrators is selected so that the time width of the output pulse signal is 500ns, so that the discharge circuit can completely release the electric charge stored in the integrating capacitor.

3. Results of the Experiment

3.1 Waveform Verification

First, use an oscilloscope to test the output of the monostable multivibrator, and obtain the two waveforms shown in Figure 5 under different input current conditions. The amplitude of the output pulse is in the form of a voltage divider to limit the amplitude to 3V to meet the requirements of microprocessor acquisition, and the pulse time width reaches the set value of 500ns. Under different input currents, the frequency of the pulse signal changes, which are 67.889kHz and 756.4kHz, respectively. The correctness of the method is verified by testing the output waveform of the monostable multivibrator, and then further experimental measurements are started.

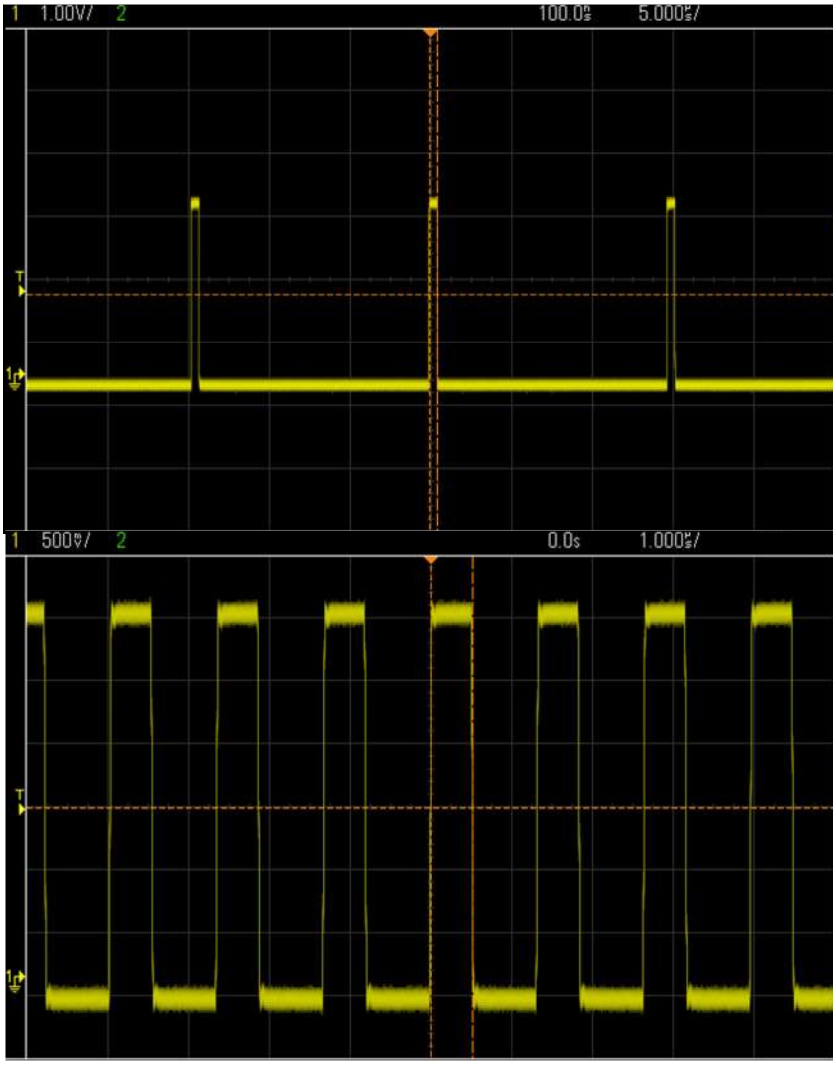

Figure 5. Output Waveform of monostable multivibrator

3.2 Measured Data

Before starting the formal measurement, the standard current source is used to calibrate the data of the measurement system. After several sets of valid data are measured, according to formula (5), the input and measurement values are used as coefficients, and the fixed parameters of the circuit are used as unknowns. Write equations, Finally, by solving its least squares solution, a calculation formula can be obtained. After the calibration, use the formula obtained from the calibration to calculate the measured value, and then start to measure the data.

Select the measurement data from -10pA to 1μA to draw the relationship between the input and the measured value, as shown in Figure 6, the fitting curve of the input and the measured value calculated by the software is, where the standard deviation of the slope is 0.000752, and the standard deviation of the intercept is 0.03583, it can be known that the linearity of the measurement system is good.

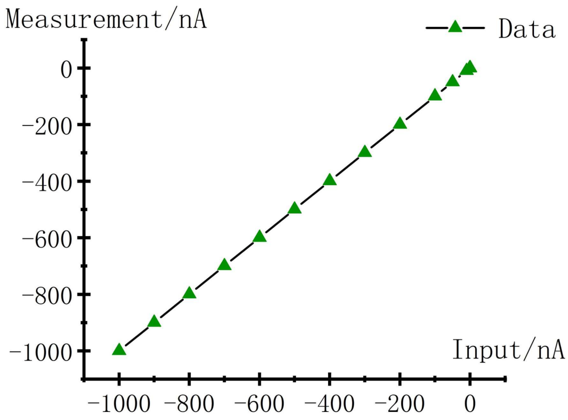

Figure 6. Linearity of Measured Data

4. Conclusion

The micro-current measurement system designed based on the current-frequency conversion method realizes the conversion of the current signal into the frequency of the pulse signal, and then obtains the frequency and calculates the measured current value through the microprocessor. The designed measurement system realizes the measurement of negative weak current without switching gears when measuring in a wide range. Analysis of the output waveform and measurement data shows that the measurement accuracy and linearity of the measurement system are good. The wide-range weak current measurement system designed this time has a very wide range of applications. The next research direction can be carried out towards the measurement of bipolar weak current to increase the application field and practicability of the system.

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