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Research on a New Circuit of Temperature Measurement

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Abstract

Temperature measurement is an important link in industrial production, also an important part of modern testing technology. The traditional single bridge circuit is already unable to meet the requirements of modern precise temperature measurement system on temperature measurement. The relation between the output voltage of general Wheatstone bridge and real strain is nonlinear. The nonlinear error will be very serious if the variance ratio of resistance ΔR/ R is very large. Platinum resistance temperature sensor as temperature element may also cause nonlinear error. And measuring ranges small for bridge. This paper designs RC filter circuit and second-order band-pass filter circuit as the core of a new type of temperature measurement circuit, introduces the principle of temperature measurement and the generation of signal source. Circuit cooperates with thermistor sensor, not only realizes the high precise temperature measurement, but also solves the measurement error of sensor produced from heating. Experiment checks that measuring precision can satisfy measurement requirements.

Keywords*: temperature measurement, bridge circuit, RC filter circuit, second-order band-pass filter circuit*

1. Introduction

Temperature measurement is an important part of the industrial production and modern detection technology. High precision temperature control has basic position in modern industrial machinery, medical engineering and energy exploration in the fields of precision measurement. It requires high precision temperature control system to control their work environment. Temperature measurement system as an important part one of the high-precision temperature control system that is particularly important in order to ensure the work stability of the core devices [1].

Bridge temperature measurement is used widely in traditional temperature control systems [2]. But its circuit anti-jamming capability is not so good, and measuring ranges small. The relation between the output voltage of general Wheatstone bridge and temperature is nonlinear in a wide range. This kind of nonlinear is caused by temperature characteristics of resistance as sensing element as well as the bridge itself [3]. So its accuracy is hard to meet requirements. Therefore, high precision temperature measurement on the safety production, ensure product quality and energy saving plays a key role. Technology and device is universally valued that can be quickly and accurately measuring temperature [4].

Based on the analysis of the traditional bridge temperature measurement circuit, this paper designs a kind of new temperature measurement circuit by using the first order filter circuit and second-order band-pass filter circuit. And fitting with thermistor sensor, at the same time, it solves the measurement error produced from sensor self-heating, achieves the high precision temperature measurement.

2. Bridge Circuit Analysis for Temperature Measurement

2.1. Bridge Circuit Nonlinear Analysis

As a temperature sensor, Platinum resistance performances stably that is widely used in the temperature measurement circuit [5]. Sensor resistance is often changed into voltage

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variation through unbalanced bridge circuit.Traditional Wheatstone single bridge temperature measurement circuit as shown in Figure 1:

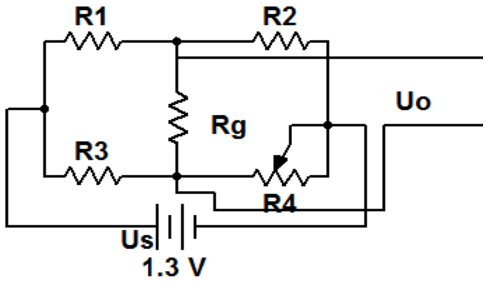


Figure 1. Single Bridge Temperature Measurement Principle Circuit

In the circuit, the change in resistance is due to reflect the change of temperature,so the temperature measurement is equal to the resistance measurement. Bridge is the traditional method to measure resistance change-ment .As showed above, three fixed resistance and a variation-resistance are formed a single element varies bridge. All resistance values are equal to the supposed R. R_g is resistance of the voltmeter. If high internal resistance digital voltmeter were used, $R_g \to \infty$. Resistance as the sensor, its change-ment can be recorded as ΔR . Bridge output voltage is U_o , supply power for bridge is U_s , output voltage is given as:

$$U_o = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4 + \Delta R}{R_3 + R_4 + \Delta R} \right) U_s \quad (1)$$

Equation (1) can be simplified for:

$$U_o = \frac{\Delta R}{4R + 2\Delta R} U_s \quad (2)$$

From Equation (2), output voltage and change of ΔR is nonlinear [6-8]. For example, $R = 100\Omega$, $U_s = 1.3V$. Where $\Delta R = 0.1\Omega$, then $U_o = 0.32483758mV$. If this as a bridge full scale output, the linearity error is 0.025%. In a similar way, where $\Delta R = 1\Omega$, then $U_o = 3.23383085mV$, the linearity error is 0.25%.

Bridge circuit output voltage and supply power for bridge are in direct proportion, so fluctuation of power will directly influence the accuracy of measurement, as well as the wiring and contact resistance. The resistance error need zero adjustment or scaling to be removed. But it produced a lot of inconvenience in the practical application [9].

2.2. Bridge Measurement Range Analysis

In the bridge, once each parameter were determined, its measuring range is not a certain value. If the measuring object were not within the scope of the voltmeter. There will be a overflow to voltmeter. Assuming that the range for the voltmeter is U_m , then from Equation (2),

$$\delta_m = \frac{4U_m}{U_s - 2U_m} \quad (3)$$

Bridge measurement range is only relevant to U_s and U_m. For example, combined and unbalanced DC bridge in FQJ type has 1.3 V built-in voltage and its digital voltmeter ranges from-200mV to 200 mV [10]. Through calculation, voltmeter ranging from 0.4706 to 0.8889. From Equation (3), measuring range of bridge is so small that cannot meet requirement.

3. A New Circuit Design

RC first order filtering circuit and the second order filtering circuit as the core temperature measurement circuit [11, 12] are designed. The circuit chooses thermistor as temperature element because it reacts sensitively and occupancies small volume in integrated system [13]. First of all, this paper uses mathematical relationship between phase that produced by RC first-order circuit [14] system and thermal resistance value to put forward temperature detection method.

3.1. RC Circuit Temperature Detection Principle

RC first-order circuit as shown in Figure 2, sine excitation signal as the input, when its frequency keep steady, after processed by RC filter, the output signal will lag a certain phase.

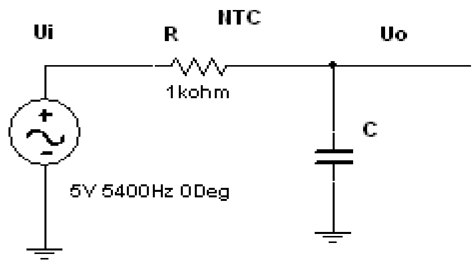


Figure 2. RC First-order Circuit

Where, the input sine excitation signal is $U_i = \sin \omega t$, resistance and capacitance in circuit is R and C, the phase between input and output is α, $U_C = A\sin(\omega t + \alpha)$, so the output voltage and α are:

$$U_O = \frac{1}{\sqrt{1+(\omega RC)^2}}\sin(\omega t + \alpha) \quad (4)$$

$$\alpha = \arctan \omega RC \quad (5)$$

Thermistor and analyte are put together, when α is measured, thermistor R is known, also analyte present working temperature [15]. Calculation of α need to transform sine of analog signal filtered by RC first-order circuit into square wave of digital signal, then through the certain logic operation and counting circuit using FPGA to pulse counting for pulse width of phase [16].

3.2. Square Wave Signal Generation Method

Sine excitation signal works as signal source of RC first-order circuit, high stability of sine signal is the result of square wave signal through the second order filters. Square wave signal is produced by the circuit that adopts active crystal oscillator and counter, its design circuit is as Figure 3.

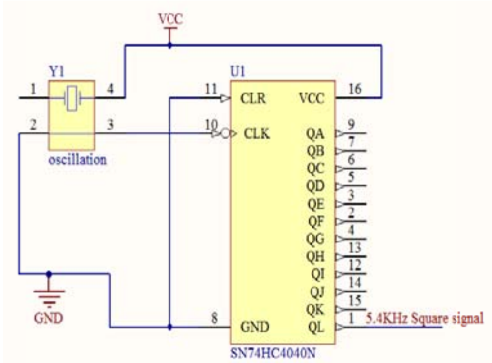


Figure 3. Design of Square Signal Produce Circuit

3.3. Sine Signal Generation Method

Quality of sine excitation signal affects the accuracy of measurement directly, so generation of the high stability sine signal is very important that high order harmonic must be filtered to it.So second-order filter circuit as shown in Figure 4 is designed to filter high order harmonic, the high frequency and low frequency noise.

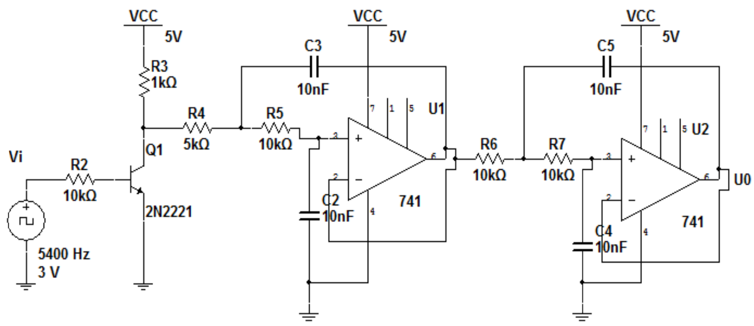


Figure 4. The Second-order Filtering Circuit

In order to get sine signal with good impact , just make once filtering is not enough, here through a band-pass filter to consolidate again.

4. New Circuit Design

4.1. Filter Circuit Analysis

In order to improve the circuit drive ability, before the filter, the NPN transistor is used. Using transistor switching characteristic to drive load, that is to say, it controls load on and off through switching between saturated zone and globe area.In the circuit, the load is met in the transistor's collector, so it gets bigger power and drive ability for circuit is enhanced.

Current flows through thermal resistance and will forces it to produces heat. The heat which generated from self heating will bring error and affects our final measurement accuracy for pulse width. Therefore, it must reduce this kind of error and the voltage loading on the both sides of thermal resistance. So twice second-order low-pass filtering is conducted. The simulation results are shown Figure 5.

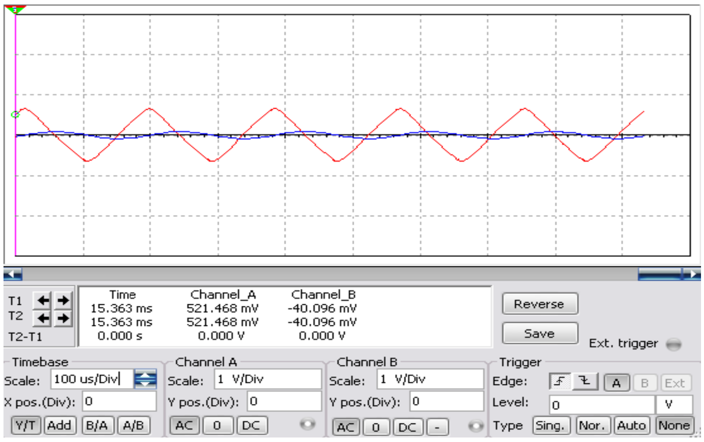


Figure 5. Simulation Result of the Second-order Filtering Circuit

According to the simulation results, after twice filtering, voltage upon RC first-order circuit reaches to the mV level, reduce the error that self heating brought .

4.2. Amplify and Comparison Circuit Analysis

As shown in Figure 6, sine analog signals are transformed into square wave signals for FPGA to identify and deal with, then through the certain logic operation and counting circuit to realize the calculation of phase. Circuit can be divided into two parts, rectangle 1 represents amplifying part, rectangle 2 represents comparison part.

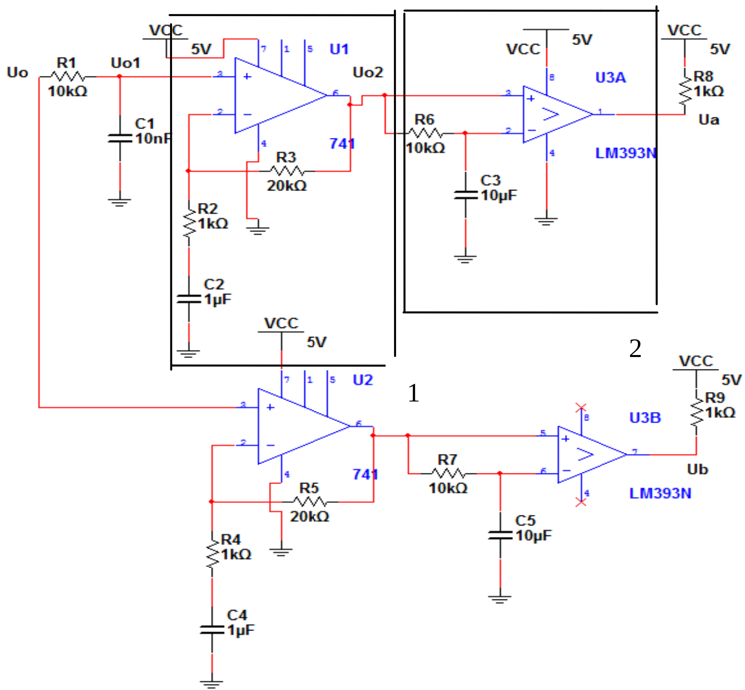
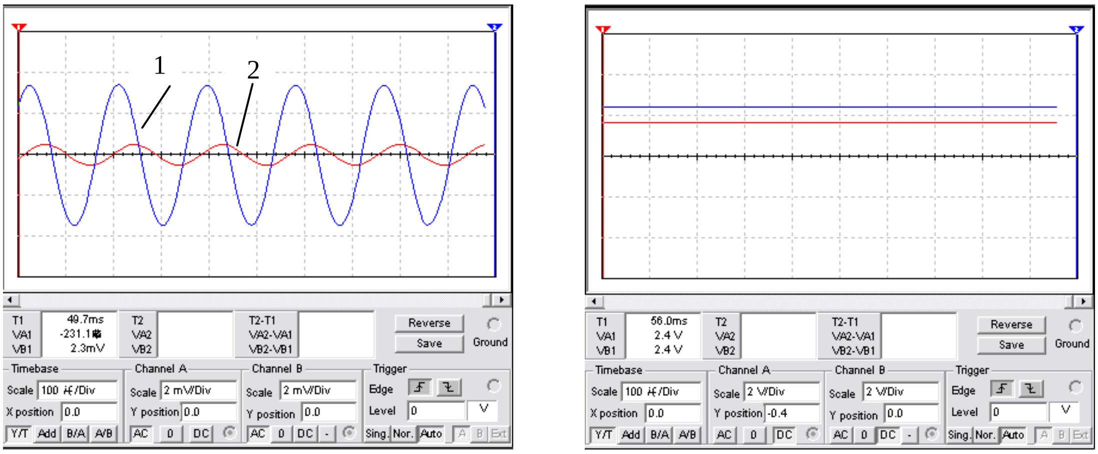


Figure 6. Circuit of Sine Analog Signals are Transformed into Square Wave Digital Signal

Sine signal source has reached the millivolt level before filtered. But in order to get high quality square wave signals after comparison circuit, the signal which filtered by RC circuit has been amplification processed. The amplification effect makes the signal sensitivity improved when doing zero crossing compares, so as to improve the quality of the square wave signal.Because the DC offset influence of op-amp, it makes the voltage across the op-amp is not equal. The small voltage difference after be amplified by op-amp will bring error to the process subsequent circuit, it may lead the second output signal to have a saturation. So full range op-amp is used. Meanwhile, op-amp negative side is met the two capacitance, as shown C2 and C3 in Figure 6. The added two capacitance only makes the circuit magnifying the AC part, keep DC part. The simulation results as shown in Figure 7, signal 1 is amplified, signal 2 is the signal that before amplified (in order not to let two DC signals have a overlap, set one of the signal down in Figure b)



(a) Result of AC amplified (b) Result of DC follows

Figure 7. Simulation Results of Amplifying Circuit

From Figure 6, where, the input voltage on thermal resistance is U_o ,output will be U_{o1} , U_{o2} after be processed by RC first-order circuit and amplifying circuit in rectangle1.

$R_3 = 20k\Omega, R_2 = 1k\Omega, C_2 = 1uF, f = 5400hz$

$$U_{o1} = U_o \cdot \frac{\frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = U_o \cdot \frac{1}{j\omega R_1 C_1 + 1} \quad (6)$$

$$U_{o2} = U_{o1} \cdot \frac{\frac{1}{j\omega C_2} + R_3 + R_2}{R_2 + \frac{1}{j\omega C_2}} = U_{o1} \cdot \frac{j\omega R_3 C_2 + j\omega R_2 C_2 + 1}{j\omega R_2 C_2 + 1} \quad (7)$$

So the magnification from U_{o1} to U_{o2} is:

$$A(\omega) = \left| \frac{712152 - 1000j}{33912 - 1000j} \right| = 0.634 \quad (8)$$

From Equation 8, phase brought from second is so small that can be neglected. So phase between U_{o2} and U_o can be equal to between U_{o1} and U_o .

The amplified signal should be compared by the circuit in rectangle 2. Because it contains DC components and high frequency sine signal will appear offset by the influence of low frequency signal.So the negative side of comparator does not directly meet with ground. Instead of, the signal through the RC first order circuit have been met with it. Then get the signal, which compared with the original signal to get square wave signal, at same time, it overcomes the signal drifting.

5. Conclusion

The new type of temperature measurement circuit which contains first-order circuit and second-order filter circuit can basically eliminate the nonlinear and small measuring range from traditional bridge temperature measurement circuit. The new circuit improves the measurement precision, eliminate nonlinear factors and influence to measurement accuracy from resistance self-heating.

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References

[1] Ye TAO, Yongchao YUAN, Ping LUO .The Temperature Measure System Based on DS18B20 and AT89S52. *Journal of Agricultural Mechanization Research*. 2007; (10): 160-164.
[2] Febriansyah, Aan Nuryadi, RatnoHartanto, Djoko. Measurement and simulation techniques for piezo-resistive micro-cantilever biosensor applications. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(6): 1301-1308.
[3] Xingsheng Li. A method of precise measurement of temperature. *Science atmospherical sinica.* 1979; 3(2): 170-174.
[4] Jianhua CHENG, Jing WANG, Xinzhe WANG. Application of double circuit in precise temperature measurement system. *Applied Science and Technology*. 2010; 37(2): 42-47.
[5] Chenquan HUA, Xuhu REN. The application of the XTR106 transmitter to the temperature measurement of a platinum thermistor and unbalanced bridge. *Industrial Instrumentation & Automation.* 2011; (5): 53-56.
[6] Jiangquan LI, Min ZHI, Jin-ling CONG, et al. Linearizing Treatment to Temperature Measurement of Platinum Thermistor. *Journal of Shihezi University (Natural Science)*. 2000; 4(2): 138-141.
[7] Cheng WEN, Shuren QIN. Linear Disposal of Wheatstone Bridge in Strain Measurement. *Journal of Chongqing University*. 2004; 27(1): 28-31.
[8] Dianhui REN, Qiaodi ZHOU, Xueting ZHANG, et,al. Nonlinear Rectification for the Circuit of Platinum Resistor in Temperature Measurement. *Chinese Journal of Electron Devices*. 2010; 33(5): 603-607.
[9] Xiaowei Liao. Study of the Sensitivity of Bridge Temperature Measure System Supplied by Constant Current Source. *China Instrumentation*. 2006; (2): 46-47.
[10] Lin LI, Zhehong XIU, Xinquan WU. An experimental study of the measurement of resistae by applying un equilibrium electric bridge. *Experimental Technology and Management*. 2007; 24(3): 31-34.
[11] Xianjun YI, Xiaoling WEN, Cuimei LIU. A high precision temperature measurement circuit design. *Electronic Instrumentation Customer*. 2008; 15(6): 72-73.
[12] Mengde LIU, Haijing HE, Libin DU. Design of a high-precision temperature measurement circuit. *Shandong science.* 2012; 25(2): 72-75.
[13] Hanbai FAN, Hanhua XIE. Study with High Precision on Three Typical Temperature Measurement Based on NTC Thermistor. *Chinese journal of sensors and actuators*. 2010; 23(11): 1576-1579.
[14] Songle WU. Application of RC Circuits. *Modern Electronics Technique.* 2004; (14): 99-101.
[15] Alimuddin, Kudang Boro Seminar, I Dewa Made Subrata, et al.Temperature Control System in Closed House for Broilers Based on ANFIS. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 10(1):75-82.
[16] Na XIU. Design of Digital Temperature Measuring Circuit Based on FPGA. *Instrumentation Technology.* 2008; (5): 51-53.