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Research and Design of High-precision Voltage Sampling Circuit for Tumor Radiofrequency Ablation Medical Instrument

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Abstract: Radiofrequency ablation is a minimally invasive procedure in which tiny radiofrequency electrodes are implanted into the diseased tissue under the guidance of medical imaging (X-ray imager, CT or ultrasound), and neutral electrodes are attached to the skin of the body to carry out radiofrequency ablation, which is carried out by forming a circuit through the human body to the diseased tissue. At present, RF ablation can be applied to lung tumors, liver tumors, kidney tumors and certain heart diseases. The core component of tumor RF ablation surgery equipment is RF power source, which is a fixed frequency sinusoidal AC output signal with a frequency of 400-500Khz. The detection technology of RF voltage is extremely important, which determines the accuracy of RF ablation energy output and energy control. In this paper, we use STM32 microcontroller as the core of acquisition and control, and propose a simple and practical sampling method with high accuracy. Moreover, we have realized to control the voltage measurement error below 1% by using the error curve fitting method for software calibration.

Keywords: RF ablation, Voltage sampling, High precision, Curve fitting.

1. Overview

This paper researches and designs the voltage sampling circuit of high precision radiofrequency ablation instrument. The voltage sampling accuracy determines the circuit, which is a very critical measurement parameter that directly affects the ablation accuracy and equipment safety. Generally, the current range of RF ablation electrode is 100 to 5000 mA, and the current is realized by changing the output voltage. Different treatments require different current range. Different treatments require different currents. For large tumor bodies, if the power is too low, it cannot generate enough heat to kill all the cancer cells. For small tumor bodies, if the power is too high, it is easy to damage too much healthy tissue.

Since the output of the control system is very much related to the sampling voltage, it is very important to improve the sampling accuracy.

2. Hardware Design

Since tumor radiofrequency ablation uses a standard sine wave with a fixed frequency, its waveform contains very few harmonic components, so the following relationship exists between its RMS and peak values

$$Vrms = 0.707 \times Vpeak$$

Therefore, the RMS value of the voltage can be obtained by measuring its peak value and thus the energy output to the lesion can be obtained. Here the sampling of voltage is divided into three parts, one part is the sampling resistor, one part is the isolation part and the last part is the AD sampling circuit.

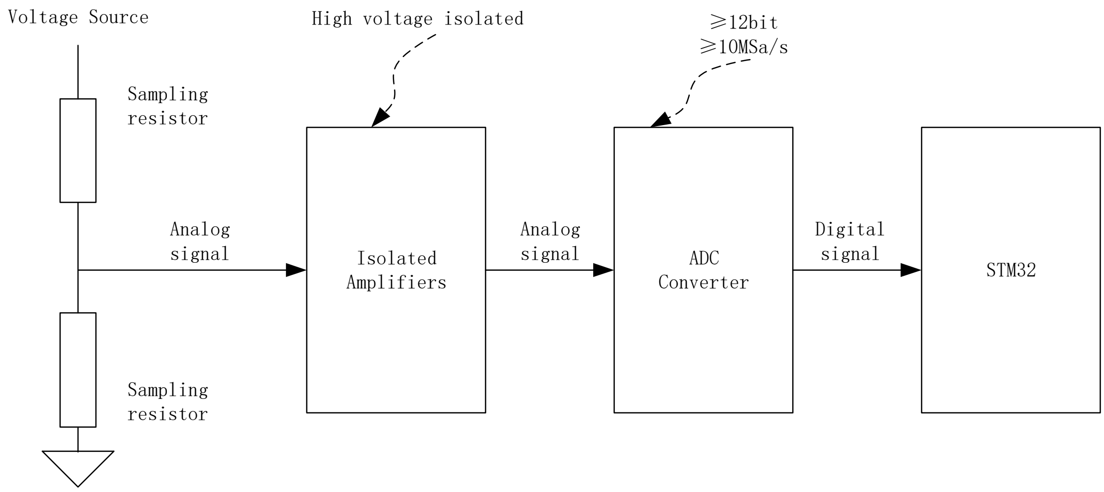

Figure 1. Block diagram of RF voltage sampling circuit

Here, considering that the sampling accuracy of the resistor is a direct influence on the overall accuracy, a high precision resistor sampling of 0.1% is chosen to improve the sampling accuracy. At the same time, in order to ensure that there is a sufficiently high accuracy, multiple resistors are sampled in parallel, which avoids the rate of influence due to the accuracy of a single resistor.

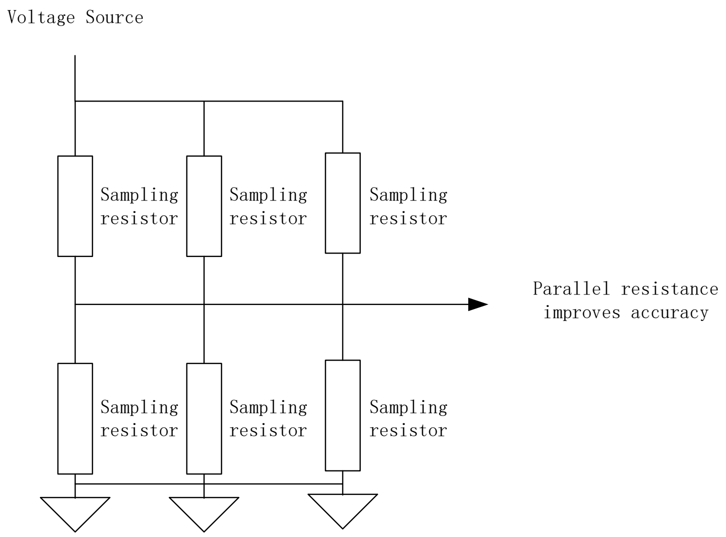

Figure 2. Sampling with multiple resistors in parallel improves accuracy

As the RF output is high power and the sampling end is weak power, they must be electrically isolated. Here, in order to obtain a higher accuracy. It is better to use integrated isolation op-amps. Here, the classic isolation op-amps are three models, ACPL-C87, AMC1311-Q1, SI8931. As shown in Table 1, we compared the gain error, nonlinearity, input offset voltage at +25℃, respectively. In fact, all three isolation amplifiers are available in both high and low precision versions. Here, since the tumor RF ablator is not a consumer product, it is not cost sensitive, so more consideration should be given to its performance in device selection. We select ACPL-C87 as the isolation op-amp.

Table 1. Comparison of main parameters of isolated operational amplifiers

Model No.	Manufacturer	Gain Error	Nonlinearity	Offset Voltage
ACPL-C87	Avago	±1%/±0.5%	0.05%	-0.3mV
AMC1311-Q1	TI	±1%/±0.3%	0.01%	±0.40.4mV
SI8931	Silicon Labs	±0.25%/±0.25%	0.01%	-0.16mV

The hardware circuit using the isolation amplifier scheme is very simple and is especially suitable in MCUs, where there is no need to make an isolated power supply. Moreover, it occupies less resources on the signaling process. Its software processing is also very simple. It transmits analog signals and is not suitable for long-distance transmission. And it involves three levels of signal processing (resistor voltage division, isolation amplification, differential amplification), so its precision cannot be very high.

However, it is very safe because it adopts a specialized isolation amplifier chip. Sampling errors can be calibrated by software, and the following sections describe how to overcome the errors using software calibration.

3. Software Error Calibration

Considering that the hardware cannot eliminate the error, it is compensated in software. Since the human tissue impedance is usually close to 60 ohms in radiofrequency ablation, the output voltage should be measured with a 60-ohm load. Twenty sampling points were set between 10 and 200 volts, with 10v intervals as a progressive value, and the measured data are shown in Table 2

Table 2. Output Voltage and Error at 60 Ohm Load

Voltage (Vrms)	Error (%)	Voltage (Vrms)	Error (%)
10	19.3	110	2.2
20	15.6	120	1.7
30	12.1	130	0.9
40	10.0	140	2.1
50	9.8	150	2.3
60	8.4	160	2.9
70	8.2	170	3.8
80	6.6	180	4.2
90	5.7	190	3.5
100	5.5	200	5.1

Considering the accuracy, all points are curve fitted with two segments, where 10 to 100 volts is the first segment and

110 to 200 volts is the second one. To further improve the accuracy, a tenth order polynomial curve is used, and the first segment of the curve fit is listed here as follows.

Fitting equation: $Y = a + b \cdot X + c \cdot X^2 + d \cdot X^3 + e \cdot X^4 + f \cdot X^5 + g \cdot X^6 + h \cdot X^7 + i \cdot X^8 + j \cdot X^9$

Parameters:

a = -291.041001091721

b = 74.150824370667

c = -8.11558162693523

d = 0.477160687845915

e = -0.0167428022018638

f = 0.000367291253702528

g = -5.08151685757529E-06

h = 4.30582796893107E-08

i = -2.03934074594803E-10

j = 4.13262904778408E-13

Correlation coefficient R2：0.999999507807927

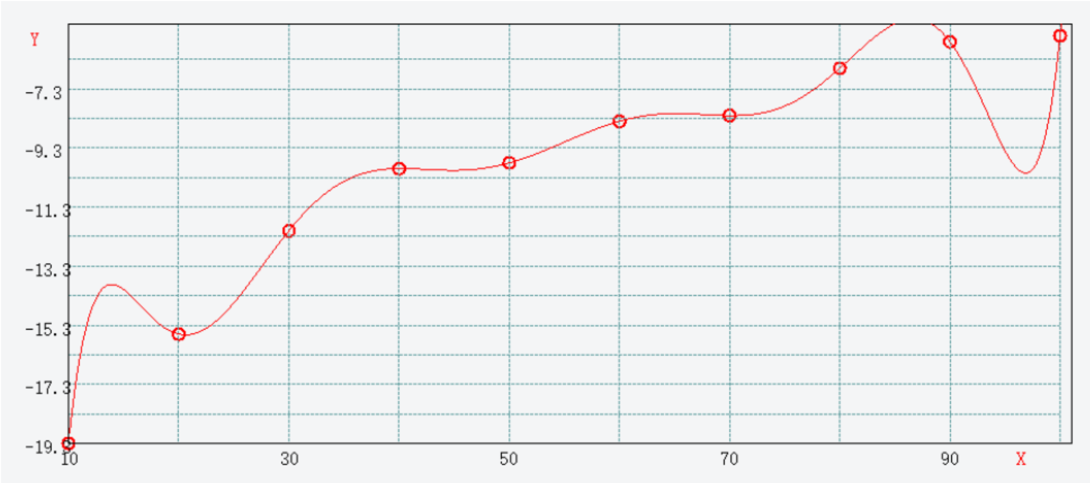

Figure 3. Error curve fitting for the first segment

4. Test

After compensating the error, we test the final error value at 60 ohm load as shown in Table 3. We can see that the maximum value of the error is 0.8%, the minimum value of the error is 0.1%, and the average error is 0.4%. Before error compensation, the maximum error value is 19.3%, the minimum error value is 1.7%, and the average error value is 6.5%. It can be seen that after calibration, the accuracy is improved by 16 times.

Table 3. Errors after software compensation

Voltage (Vrms)	Error (%)	Voltage (Vrms)	Error (%)
10	0.8	110	0.4
20	0.5	120	0.2
30	0.6	130	0.3
40	0.2	140	0.4
50	0.2	150	0.5
60	0.3	160	0.2
70	0.5	170	0.5
80	0.2	180	0.5
90	0.1	190	0.6
100	0.3	200	0.7

5. Conclusion

Voltage sampling for radiofrequency ablation can be performed using isolated op-amps, but the accuracy is not high and needs to be calibrated using software. Fitting a function to the error and compensating for it with software can greatly improve the accuracy, which is 16 times higher. The use of software compensation is essential in sampling circuits for RF ablation.

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