Design of AC Voltage Tester Based on STM32

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Abstract: This design is a tester designed to accurately measure AC voltage signals. This design uses STM32 as the core processor, uses a voltage transformer to step down the original signal, and combines the MCP6292 operational amplifier to cleverly design a signal conditioning circuit so that the input voltage can meet the voltage measurement range of STM32. The analog signal is sampled at equal time intervals by the successive integration algorithm to obtain its effective value. Then through the built-in AD conversion module on the STM32 processor chip, the signal is converted to analog to digital. Finally, the converted value can be displayed on the screen through the LCD, and the measured data can be displayed on the upper computer terminal at the same time. Through the observation of the measured data, it can be found that the design can accurately measure the AC voltage. Compared with the traditional measurement method, the design can improve the measurement accuracy and improve the stability and power consumption.

1. Introduction
With the vigorous development of the power industry, the current demand for electricity in the household and commercial power industries has increased extensively. The collection and accurate measurement of AC voltage are becoming more and more important[1]. The traditional method of measuring AC voltage is to use the AC file of a multimeter[2] to measure. However, rectifier components must be used in the measurement. And its own storage capacity is small, the accuracy is not high, and can not achieve automatic measurement. Although the 8051 single-chip microcomputer that appeared later can also be measured, it itself is limited due to insufficient on-chip RAM and other factors, and its performance cannot be fully utilized.

This design uses a scheme to measure AC voltage based on STM32[3][4]. It not only realizes the functions of step-down, acquisition, transmission, analog-to-digital conversion and display of AC voltage, but also realizes higher accuracy of AC voltage measurement value. Compared with traditional measurement tools, this design has the characteristics of small volume, large storage capacity, low power consumption and high measurement accuracy[5]. It can realize automatic and accurate measurement in real-time field and has good use value.

2. Scheme design of voltage tester
The purpose of this design is to reduce the error caused by the traditional multimeter measuring voltage and improve the measurement accuracy. The purpose is to measure the RMS of AC voltage efficiently and conveniently. Its working process is that the signal source is stepped down by the voltage transformer[6] and the signal conditioning circuit[7] is used to meet the voltage measurement range of the single chip microcomputer. Using the successive integral algorithm[8][9], the step-down
analog voltage is sampled at equal intervals and then integrated to obtain the effective value\textsuperscript{[10]} . Finally, using the LCD liquid crystal display to display the converted value of the AD module, and sending the measurement results back to the host computer to the virtual terminal for display. Figure 1 is the schematic diagram of the scheme design.

3.System hardware design

3.1. Signal conditioning circuit
Because the voltage measurement range that the STM32 on-chip AD conversion module can withstand is 0–3.3V. Therefore, this design uses a voltage transformer to pass the AC voltage signal through R1 on the left side of the transformer to make the voltage signal into a current signal. After passing through the transformer, use R2 to convert it into the required voltage range. After the attenuation of the voltage transformer and the calculation of the proportional calculation circuit. Finally, through the RC filter circuit to filter out the interference signal, the resulting voltage can be output to the ADC channel. According to the turn ratio of voltage transformer and the input voltage range of ADC, it can be calculated that R1 = 300K, R2 = 100R, R3 = 20K. R is a sliding rheostat, and the resistance value can be adjusted to adjust the proportional circuit. When the AC voltage signal is positive, after attenuation, the diode D1 turns on, and the circuit becomes a voltage follower at this time. When the signal is negative, diode D2 is on, and the circuit becomes a proportional circuit. The signal conditioning circuit is shown in figure 2.

3.2. ADC module
AD conversion adopts STM32 on-chip integrated AD module. STM32 contains a total of 3 ADCs. In order to increase the sampling rate, this design adopts ADC dual mode acquisition. Since STM32 can only measure 0–3.3V voltage, the AC voltage is attenuated and then filtered and then processed before
being sent to the ADC module for conversion. The ADC module in this design is a unipolar 12-bit successive approximation analog-to-digital converter with up to 18 channels, which can measure 16 signal sources and 2 internal signal sources. It can support single conversion and continuous conversion mode. The AD conversion in this design adopts the dual ADC synchronization rule mode to collect signals. The measurement range is the converted voltage of 0~3.3V, and the display error is 0.001V.

3.3. STM32 module
The main control chip selected in this design is the single-chip microcomputer STM32F103VET6, produced by Italian Semiconductor Co., Ltd. This series is based on the high-performance Cotex-M3 core single-chip microcomputer developed by ARM Company. 512KB Flash memory is integrated in the chip, with 72MHz main frequency with UART, SPI, I2C and other communication interfaces. It has the characteristics of high performance and low power consumption. The function of STM32 single chip microcomputer in this design is to send the signal conditioned analog signal into its own on-chip ADC. After being converted into a digital quantity, the LCD display is controlled on the display screen, and the serial port terminal is made to output relevant information. The clock circuit of single chip microcomputer can effectively guarantee its operation. The entire STM32 control system includes power supply module, crystal oscillator circuit, download circuit and reset circuit.

3.4. Communication interface
This design uses UART and I2C as the communication interface to communicate with STM32. After passing through the signal conditioning circuit, the attenuation signal is first sent to the ADC channel, and after the conversion is completed, it is transmitted to the virtual terminal through the UART interface. At the same time, the data is also sent to the LCD display through the I2C interface to display the converted measured value. The LCD display module display is controlled by the FSMC interface of STM32. Within the MCU, the Cortex-M3 kernel connects one end of the FSMC through an AHB high-speed bus, and the other end of the FSMC is connected to an external bus for extended memory. FSMC can turn LCD into a memory with an address space, which is convenient for MCU to operate it.

4. Software programming
The software design part of this design is mainly composed of the following three parts. First initialize each hardware peripheral, initialize the clock, and peripherals such as GPIO pins. Secondly, the effective value of AC voltage should be obtained by integrating the sampled AC voltage value with the successive integration method. Finally, the program design of the AD sampling conversion process and the driver of the display screen. The program part of this design software mainly explains the process of obtaining the effective value by the successive integration method and the process of AD conversion.

4.1. Sampling by successive integration method
For sinusoidal AC signal, the effective value of voltage is to let direct current and alternating current pass through the same resistance in the same time, so that the heat consumption is the same. Then the DC voltage can be regarded as the effective value of the alternating current. Based on a differential time dt, the work done by AC voltage is

\[ dW(t) = \frac{u^2(t)}{R} dt \]  

Do work for a long time T

\[ W = \int_0^T \frac{u^2(t)}{R} dt \]  

This work is equal to the energy produced by a DC voltage \( U_{RES} \) on R during the time T

\[ W = \frac{T U_{RES}^2}{R} \]
According to the above formula, the effective value of AC voltage is

\[ U_{RMS} = \frac{1}{\sqrt{T}} \int_0^T U^2(t) \, dt \] (4)

According to the sampling theorem, by sampling the instantaneous value of \( U(t) \) at equal intervals, a time-discrete signal sequence can be obtained. Finally, the true effective value of \( U(t) \) is obtained by successive integration. If the \( U(t) \) signal is sampled at \( N \) points at equal intervals of \( \Delta t = T/N \) within a period \( T \), a discrete sequence can be obtained

\[ U(n) = u(n \cdot \Delta t) \quad (n = 0, 1, 2, 3, \ldots, N-1) \] (5)

According to the quadrature formula of successive integral method, we can get

\[ U_{RMS} \approx \frac{1}{\sqrt{T}} \Delta t \cdot \sum_{n=0}^{N-1} [U^2(n) + U^2(n + 1)] \] (6)

64 points are sampled at intermediate intervals in this design, then there is

\[ U_{RES}^2 T = \frac{\Delta t}{2} \left[ u_0^2(t) + 4 \left( u_1^2(t) + u_2^2(t) + \ldots + u_6^2(t) \right) + 2 \left( u_7^2(t) + u_8^2(t) + \ldots + u_{63}^2(t) \right) \right] + \text{RN} \] (7)

Among them, RN is the remainder, because the accuracy of the STM32 on-chip ADC is 0.7mv, and collecting 64 points at equal intervals in each cycle can meet this accuracy requirement.

4.2. ADC collection and conversion

First, initialize the STM32 peripherals. This design involves external devices such as ADC, GPIO and EXTI. In addition, the system timer, UART and other peripherals are also used. The ADC acquisition process of this design is to reset the system after initializing each peripheral. Then configure the ADC clock, ADC channel and sampling time. After the timer interrupt is turned on, the ADC conversion is completed in the interrupt subroutine after the sampling pulse arrives. Finally, the data after processing is completed the converted data to the LCD display while transmitting data to the display terminal. The procedure flow is shown in Figure 3.
5. The system collects the data and the experiment result analysis

Take the positive and negative 220 V sinusoidal alternating current as an example. Selection voltage transformer turns ratio of 67: 1, after the step-down transformers, the AC voltage maximum amplitude of -3.3V-3.3V. This design performs data analysis on the sampled analog signal, collecting the analog voltage of about 0.5V every time. Because after the signal conditioning circuit output, converted into the value of the on-chip ADC are 0 ~ 3.3V. Therefore, after collating and summarizing the collected data, the data obtained are as follows. Since the conversion time of the ADC is related to the input clock and sampling time of the ADC. The conversion time is equal to the sampling time plus 12.5 cycles. When ADCLK is 12MHZ, the sampling time is set to 1.5 cycles, and the total conversion time is 1.17us. Because the ADC is 12-bit. The 12-bit full scale corresponds to 3.3V, and the 12-bit full scale corresponds to a digital value of 2^12. The value 0 corresponds to 0. If the converted value is X and the analog voltage corresponding to X is Y, then Y = (3.3 * X) / 2^12. According to the measured voltage value, the measured data is plotted as shown in Table 1.

| Original voltage (V) | Theoretical voltage (V) | Analog after conversion (V) | multimeter measurement (V) | Error (V) |
|----------------------|-------------------------|----------------------------|---------------------------|-----------|
| 3.3                  | 0                       | 0.002415                   | 0.03                      | 0.002     |
| 1.6                  | 0.5                     | 0.495486                   | 0.52                      | 0.015     |
| 0.5                  | 1.0                     | 1.003048                   | 1.12                      | 0.003     |
| 0.1                  | 1.5                     | 1.511618                   | 1.52                      | 0.011     |
| -1.7                 | 2.0                     | 2.008188                   | 2.03                      | 0.008     |
| -2.0                 | 2.5                     | 2.510924                   | 2.52                      | 0.010     |
| -2.5                 | 3.0                     | 3.054272                   | 3.09                      | 0.542     |
| -3.3                 | 3.3                     | 3.291945                   | 3.28                      | 0.012     |

Observing the data shows that, compared with a multimeter, this design effectively improves the accuracy of measuring voltage. According to the turns ratio of the transformer, the AC voltage before step-down can be obtained. Error analysis: After collecting the input voltage many times, comparing the theoretical value and the actual measured value, it is found that the cause of the error is mainly composed of several reasons. First, the parameters of the components in the circuit may be affected by the temperature in the environment, resulting in the error between the measured value and the theoretical value. Second, random error. Observing Table 1 shows that some of the value errors are relatively large, which may be caused by humans during the measurement process. Third, the system error, when the voltage across the signal conditioning circuit is fed into the ADC chip STM32, there will be a sampling and quantization error in the AD conversion process. Error resolution: First, take the average of multiple measurements. Second, the effective value of the AC voltage can be solved by the root mean square algorithm and then sent to the STM32 on-chip ADC, that is, the effective value is first squared and then summed to obtain the effective value average value and then squared. It can also reduce errors. Third, before the AC voltage decays, the high-order harmonics in the AC signal are filtered. It can also improve accuracy.

6. Concluding remarks

This design is a tester designed to measure AC voltage based on STM32. This tester can measure not only standard sinusoidal signals effectively, but also non-sinusoidal signals with the same accuracy. This design can achieve the voltage test range of STM32 after the AC signal is attenuated to analog signal. The MCU itself contains an analog-to-digital conversion chip, which can achieve the purpose of measurement without an external chip. It can be seen from the experimental results, the measured value of the voltage collected by this design is basically consistent with the theoretical voltage, and the accuracy is very high. It can be seen that it is a true effective value conversion tester worth promoting. It can be used on precision instruments such as digital multimeters.
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