Construction of a Ultrasonic Gas Flowmeter

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Abstract: In this paper, a new method on how to design ultrasonic gas flow meter is presented. Ultrasonic sensor with large area and center frequency 120kHz is selected and ultrasonic sensor driving circuit based on IRF7389 is designed to drive the sensor, the received ultrasonic signal can reach 1000mv in the distance of 30cm, thus can make the amplifying circuit easy to design. In the ultrasonic receiving circuit, the no inverting amplifier is used to realize preliminary amplification; followed by the second-order band pass filter with the center frequency for 120kHz to filter out the noise, gain adjustable amplifier circuit is designed based on digital potentiometer, ultrasonic signal after comparison circuit outputs square wave to control chip time TDC-GP2 to achieve time interval measurements. Finally, the system is calibrated and the calibration results show that the measurement accuracy is 1%.

1 INTRODUCTION

Ultrasonic gas flowmeter is a new type of gas flow meter. It has the advantages of wide diameter measurement range, without changing the fluid flow state for no measuring element in the fluid, simple structure, easy installation and maintenance and other advantages. But it also has some technical difficulties, such as the measurement precision sensitive to noise for small output of the ultrasonic transducer. In this paper, the author will put forward a new method on how to design an ultrasonic gas flowmeter, solve the problems mentioned above and realize the high precision measurement[1] [2].

2 INTRODUCTION OF THE WORKING PRINCIPLE OF ULTRASONIC FLOWMETER

Flow measurement based on ultrasonic has several types: phase difference method, speed difference method, frequency difference method, ultrasonic Doppler method and so on [3] [4] [5]. The design in this paper uses the time difference method, the system structure is shown in figure 1.

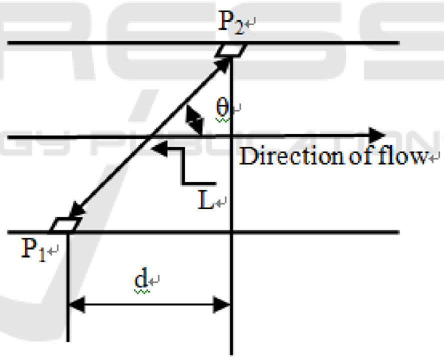

Fig. 1 principle diagram of time difference method.

P1, P2 are two ultrasonic transducers, v is the flow velocity of fluid, and θ is the angle between P1P2 and the fluid flow direction; d is the linear distance between P1 and P2, L is the vertical length between P1 and P2, c is the sonic velocity. First, P1 is the transmitter and P2 as the receiver, propagation time is downstream time t1:

$$Q = v \cdot S = \frac{L}{2\cos\theta}\left(\frac{1}{t_1} - \frac{1}{t_2}\right) \cdot \pi \cdot \left(\frac{\sin\theta L}{2}\right)^2$$

In the formula above, the influence of the temperature change to the measuring result is avoided, and the accuracy of the flow measurement is ensured.

3 THE OVERALL DESIGN OF ULTRASONIC GAS FLOW METER

The overall structure of ultrasonic gas flow meter is shown in Figure 2, including ultrasonic transducer drive circuit, analog switch, signal processing circuit, single-chip microcomputer, timing circuit, display circuit.[6]

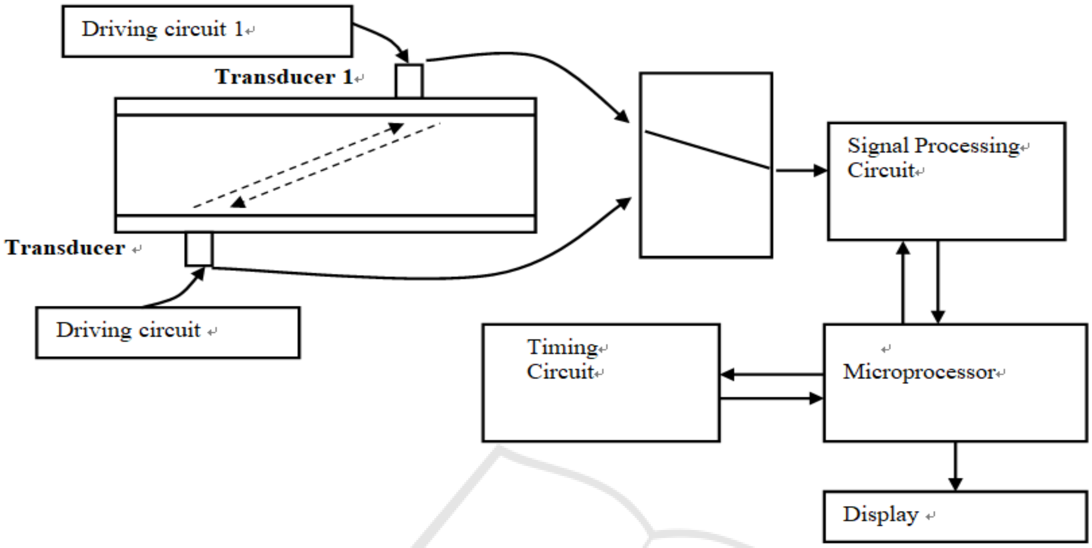

Fig. 2 the overall block diagram of ultrasonic gas flow meter.

4 THE CHOICE OF THE ULTRASONIC TRANSDUCER AND DESIGN OF THE DRIVING CIRCUIT

4.1 Selection of Ultrasonic Transducer

Because of measuring gas flow, the center frequency of the transducer can only be in the range of tens KHz to hundreds KHz. In order to transducer are: (1) the center frequency: 120 kHz; get large output signal, the area of transducer chip must be as large as possible, with large driving power, strong ultrasonic signal is output, which will alleviate the burden of the sequential circuit and improve the stability and accuracy of the overall system signal.

In this design, the diameter of the transducer wafer is about 15mm. The performance parameters of the selected ultrasonic.

(2) the driving pulse amplitude: 300V; (3) band width: 2 KHz; (4) the static capacitance: 500p (2600 ohm impedance equivalent in 120 kHz).

4.2 Ultrasonic Transducer Drive Circuit Design

It is not easy to produce amplitude 300V pulse directly. In this design, the basic ideas is to produce small amplitude square wave with same frequency first, then a transformer is used to realise 300V pulse after amplitude amplification and power amplification. The diagram of driving circuit is shown in Figure 3.

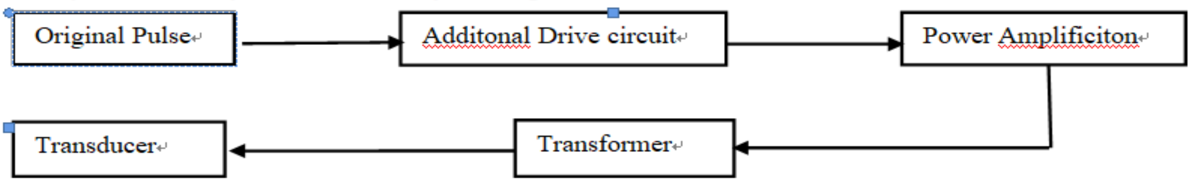

Fig. 3 Integral block diagram of driving circuit .

4.3 Primary Pulse Generation Circuit Design

The initial source of the driving pulse is the pin of the single chip microcomputer Msp430f149 which outputs the +3.3V square wave pulse with 120 KHz frequency. Each transducer of the driving pulse is divided into two parts, for a transducer using the microcontroller pin P4.3 and P4.4, and the other one using pin P4.5 and P4.6. The drive pulse is shown in figure 4:

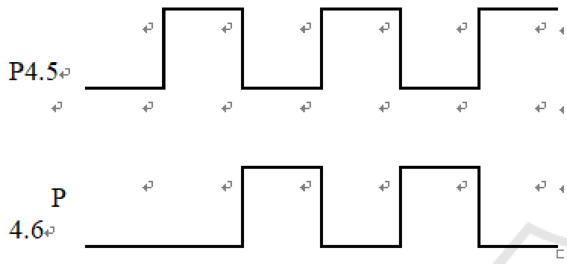

Fig. 4 Initial driving pulse

4.4 Power Amplifier Circuit Design

The voltage of transformer primary coil is +30V while the transform ation ratio is 10:100. MCU sends out +3.3V pulse amplitude needing amplitude amplification and power amplification before reaching +30V. IRF7389 power field effect tube is used to realise power amplifier, whose parameters are VDSS = + 30V, on the resistance RDS (ON) = 0.029 ohm (N channel) and 0.058 ohm (P channel), ID = 4A. Due to its large junction capacitance (1000PF), IRF7389 needs 15mA to work. A single pin of Msp430F149 can only output the maximum current 3mA, unable to meet the requirements. Therefore additional driver chips must be used. In this paper, the TC4426EOA field effect transistor driver is selected, and the driving circuit schematic diagram is shown in Figure 5.

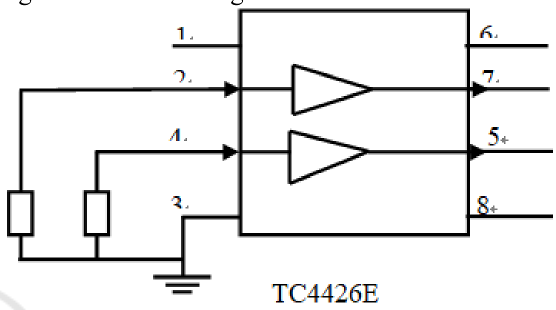

Fig. 5 Schematic diagram of IRF7389.

As shown in Figure 5, driving circuit based on TC4426EOA converts the +3.3 V signal to +15V pulse with 100mA current output. It can drive the IRF7389 power circuit, the power application circuit with the transformer is shown in Figure 6.

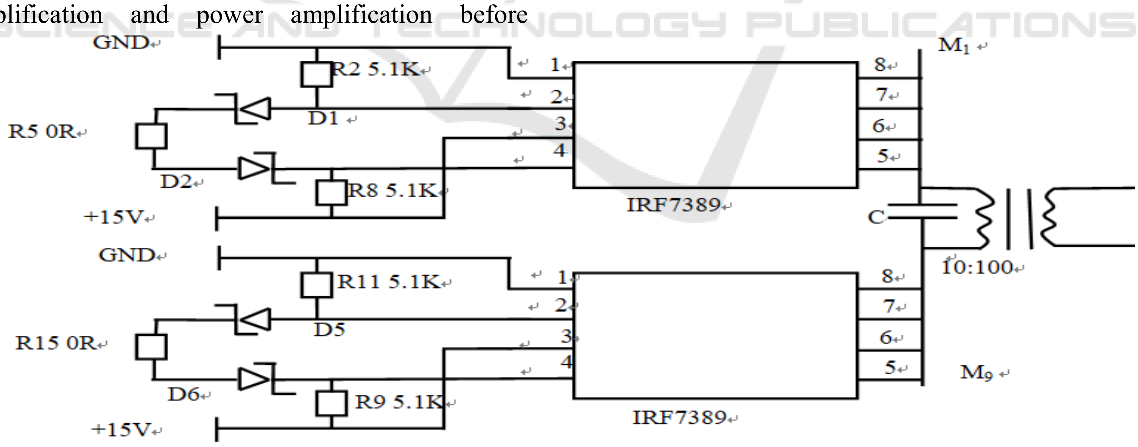

Fig. 6 Power amplifier and transformer circuit diagram.

Two pieces of IRF7389 is used in the circuit. Each chip comprises two power field effect tube, a p-channel and an n-channel tube. When it outputs high level signal, n-channel tube works. When the low level signal is outputs, p-channel tube works. Therefore, it can guarantee the value of the voltage between the M1 and M9 is 30V; 300V amplitude can be gotten after 10:100 transformer. At same time, the current can meet the requirements to drive ultrasonic transducer. The output signal of the ultrasonic transducer is shown in Figure 7. The amplitude of the signal has reached the peak-peak value of 1V, which provides convenience for the design of the subsequent processing circuit.

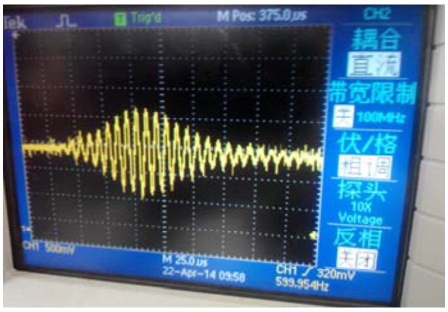

Fig. 7 Ultrasonic signals received by the receiving transducer.

5 SIGNAL PROCESSING CIRCUIT DESIGN

Signal processing circuit is the ultrasonic signal receiving and processing circuit, including: switching circuit, no-inverting amplifier circuit, filter circuit, variable gain amplifier and comparison circuit, timing circuit, LCD display circuit, and several other parts. The overall structure of the receiving circuit is shown in Figure 8.

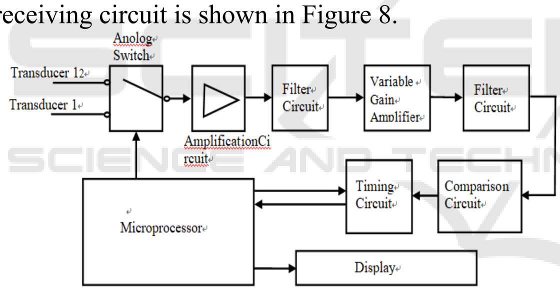

Fig. 8 Overall block diagram of signal receiving circuit.

5.1 Signal Amplification Circuit Design

Midpoint voltage single supply noninverting amplifying circuit is used in the design who can realize the signal extraction and amplification because of its large input impedance and can avoid the use of negative power supply to reduce the noise of the system and save the use of components. Operational amplifier in this design is MAX4331, circuit as shown in Figure 9.

The relationship between the input signal and the output signal of the circuit can be calculated by the following formula:

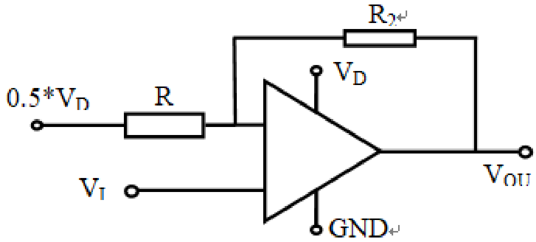

Figure 9 Midpoint voltage no inverting amplifier circuit diagram.

$$\frac{V_{OUT}-(V_{IN}+\frac{V_{DD}}{2})}{R_2}=\frac{(V_{IN}+\frac{V_{DD}}{2})-\frac{V_{DD}}{2}}{R_1}$$

$$V_{OUT}=V_{IN}(1+\frac{R_2}{R_1})+\frac{V_{DD}}{2}$$

Through the above formula, we can know that the output signal is superimposed on the half power supply, so in single power circuit positive and negative signal can be amplified at the same time, the magnification times are 2. Amplification factor is small because non inverting amplifier input impedance is too large to lead to large noise that will cause difficulty to design the later filter circuit.

6 COMPARISON CIRCUIT DESIGN

In order to accurately measure the time interval, it is necessary to have a zero crossing comparison circuit, after which the ultrosnic signal is converted into square wave to trigger time chip to record the time of transmission. The comparator in the comparison circuit is MAXIM Company’ s MAX998, the circuit as shown in fig.

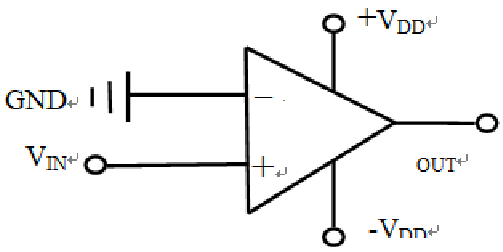

Fig. 10 Schematic diagram of zero crossing.

7 TIMING MODULE CIRCUIT DESIGN

Time chip TG-2 is used in this design to measure time difference. TG-2 has two kinds of modes. In this design, mode 2 is choiced: 50ps time resolution, 500ns - 4ms measurement range, rising edge or falling edge trigger. The interface circuit between microcomputer MSP430f149 and time chip TG-2 circuit is shown in figure .

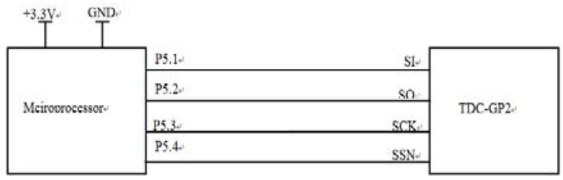

Figure 11 TDC-GP2 and MSP430 MCU SPI interface circuit.

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