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Design of transmitting and receiving circuit of ultrasonic transducer based on STM32

Xiaohe Kong¹, Xisheng Li^{1,2,*} and Ruochen Zhou¹

¹ School of Automation and Electrical Engineering, University of Science and Technology Beijing, Beijing 100083, China

²Beijing Engineering Research Center of Industrial Spectrum Imaging, Beijing 100083, China

*Corresponding author's e-mail: lxs@ustb.edu.cn

Abstract. In order to meet the needs of ultrasonic in industrial detection, an ultrasonic transmitter and receiver circuit based on STM32 is designed. The transmitting circuit is controlled by the optocoupler control isolation circuit and the MOSFET drive circuit to generate high-voltage excitation pulses to drive the ultrasonic transducer; the receiving circuit which achieves Processing of ultrasonic echo signals includes a limiter circuit, a preamplifier circuit, a Butterworth band-pass filter circuit and an automatic gain circuit, etc The actual test shows that the ultrasonic excitation signal generated by the system has the characteristics of low noise and steep waveform. The processed echo signal is clear, the system performance is good and the structure is simple, stable and reliable.

1. Introduction

Ultrasonic detection technology is widely used in robot obstacle avoidance, geological exploration, vehicle positioning and navigation and other fields. In recent years, with the improvement of the requirements for detecting range accuracy, in order to obtain range information more accurately, the requirements for ultrasonic technology have been increasing. Ultrasonic transmitting and receiving circuit is the core technology in ultrasonic detection. Therefore, how to obtain high-voltage pulse signal with small power supply voltage and how to improve the performance of receiving circuit are always the research hotspots and difficulties. Literature [1] proposes an integrated transceiver ranging system based on STM32. However, in the transmitting circuit, the ultrasonic excitation transmitting signal attenuation is large, the resonant frequency of the transducer is low, and the application is limited. Literature [2] puts forward a design of ultrasonic emission and control circuit in theory, but it needs experimental verification. In literature [3], an ultrasonic transmitting circuit combining MOSFET drive circuit and push-pull transform circuit are used, but the transmitting circuit is more complex and the transformer has a large volume. To solve these problems, a kind of ultrasonic transmission and receiving circuit based on STM32 is designed. STM32F429 whose highest frequency of the system can reach 180MHz is selected as the main control chip in the control circuit, so it can achieve a high accuracy. The transmitting circuit is a matching circuit composed of inductance and MOSFET, with simple structure, small attenuation and steep waveform of the generated ultrasonic excitation pulse. The receiving circuit adopts sixth-order Butterworth filter, which has good filtering effect.



2. The overall design of the circuit

The overall structure of ultrasonic transmitting and receiving circuit is shown in Figure 1, mainly including STM32 control circuit, memory module, transmitting circuit, transceiver integrated ultrasonic transducer and receiving circuit. Among them, STM32 control circuit is mainly responsible for sending optocoupler control signal and PWM output signal, performing ADC conversion and calculating distance information. The storage module will store the processed data in NAND FLASH. The function of transmitting circuit is to drive ultrasonic transducer by generating high voltage excitation pulse. The transceiver integrated ultrasonic transducer adopts piezoelectric ceramic ultrasonic transducer, which converts electric energy into mechanical energy when transmitting ultrasonic wave, and converts mechanical energy into electrical signal when receiving echo signal. The main function of the receiving circuit is to process the received echo signal so that the control module can further process the echo signal and calculate the transit time.

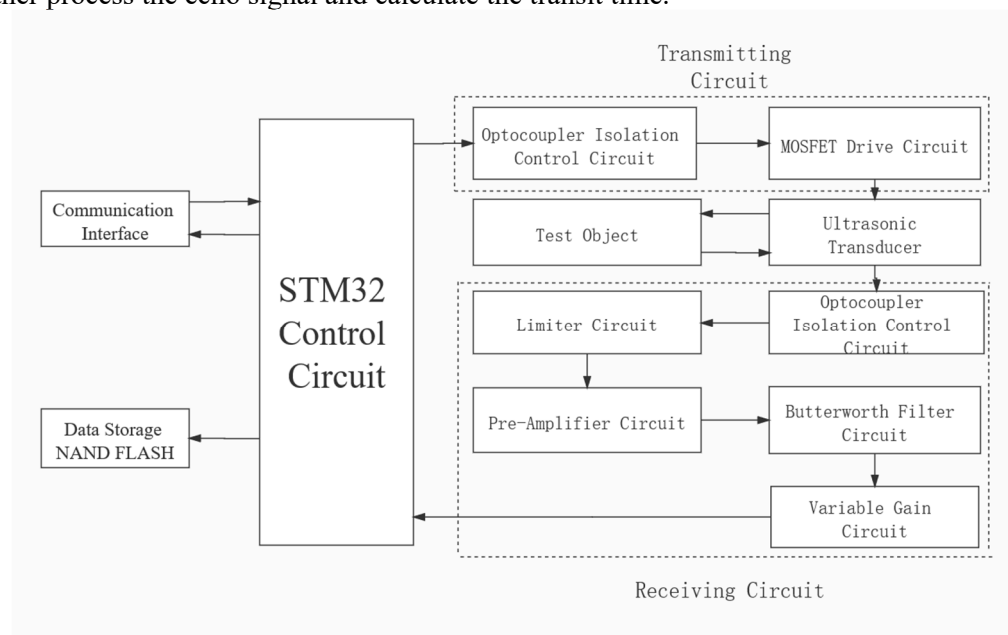


Figure 1. The overall structure of ultrasonic transmitting and receiving circuit.

3. The design of the transmitting circuit

The transmitting circuit mainly includes optocoupler isolation control circuit and MOSFET drive circuit.

3.1. Optocoupler control isolation circuit

The optocoupler control isolation circuit not only plays a control role but also plays a role in isolation in the ultrasonic ranging system. On the one hand, because the ultrasonic transducer integrated with the transceiver is used, the control signal and the optocoupler control circuit need to work together to control the conduction of the ultrasonic transducer transmitter circuit and receiver circuit; on the other hand, due to the PWM generated by STM32. The PWM is converted into a high-voltage pulse signal through the MOSFET drive circuit. In order to prevent the single-chip microcomputer from being damaged by the high-voltage signal, an optocoupler circuit is required to isolate the single-chip microcomputer to avoid electromagnetic interference between different circuits.

The optocoupler relay used in this system is MOC3063, which has the characteristics of high speed, high withstand voltage and low power consumption. The working state of the optocoupler circuit is controlled by the single-chip microcomputer output control signal, which can effectively isolate the electromagnetic interference between the circuits and ensure that the shape of the excitation pulse signal and the echo signal does not change basically. The specific implementation circuit is shown in

Figure 2.

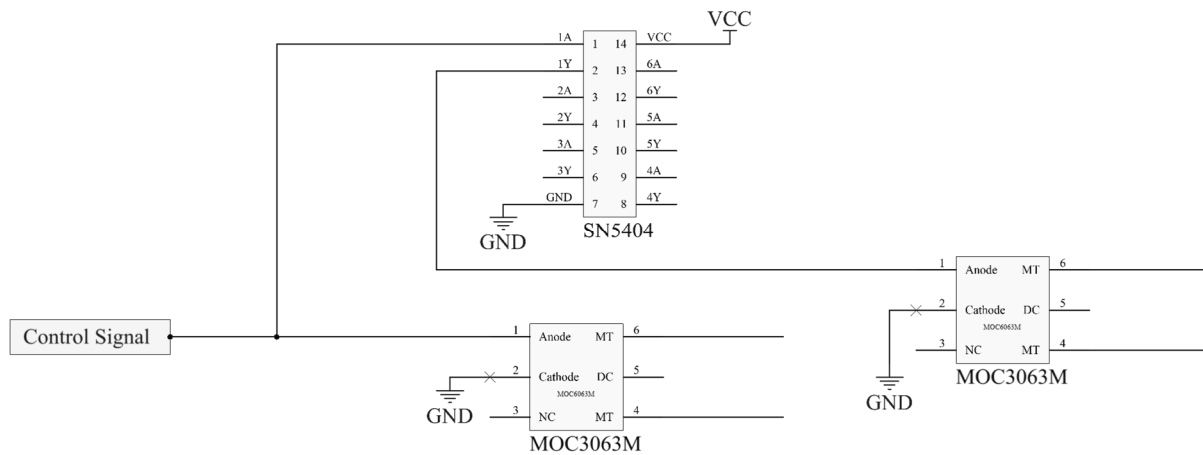


Figure 2. Optocoupler control isolation circuit.

3.2. MOSFET drive circuit

The MOSFET excitation circuit is shown in Figure 3. The simulation waveform is shown in Figure 4.

Q_1 is an N-channel enhancement type MOSFET, and V_1 provides a constant 24V voltage to the circuit. A square wave with a peak-to-peak value of 10V and a duty cycle of 70% generated by STM32 and a voltage comparator is connected to the gate of the MOSFET to control the turn-on and turn-off of Q_1 . When the driving signal of Q_1 is low level, Q_1 is turned off, V_1 passes through L_1 and R_3 , and L_1 is charged at the same time. Since the resistance of R_3 is large, a small current flows in inductor L_1 at this time. When the driving signal of Q_1 changes to a high level suddenly, Q_1 is turned on, and the current flowing through L_1 increases instantly. Due to the characteristic of the inductance that hinders the change of current, a left-negative and right-positive electromotive force will be generated on L_1 , which provides excitation for the transducer U_1 . The voltage drives the transducer to emit ultrasonic waves[4]. In the figure, the parallel resistance of the transducer can absorb the tail vibration and reduce the interference of the transmitted signal to the echo signal reception.

The calculation method of output voltage is as follows:

First, the loop composed of V_1 , L_1 , and R_1 can have the following relationship, where i is the loop current of the loop:

$$V_1 = L_1 \frac{di}{dt} + R_1 i$$

It can be seen from Figure 3 that the output voltage of the circuit can be approximately equivalent to the voltage across R_1 , then:

$$U_o \approx R_1 i$$

It can be derived:

$$U_o = V_1 - L_1 \frac{di}{dt}$$

According to the above equation, as long as you select the appropriate inductor and FET, you can get the desired output voltage.

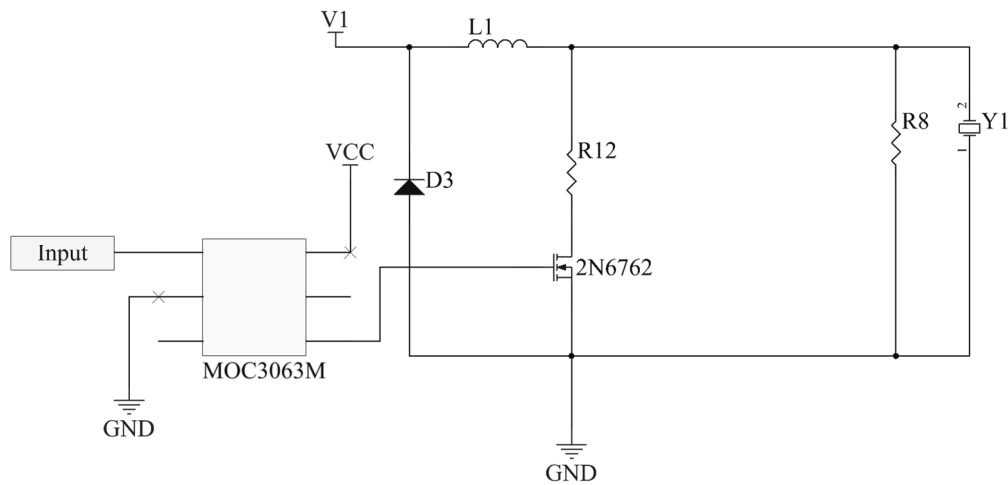


Figure 3. Optocoupler control isolation circuit.

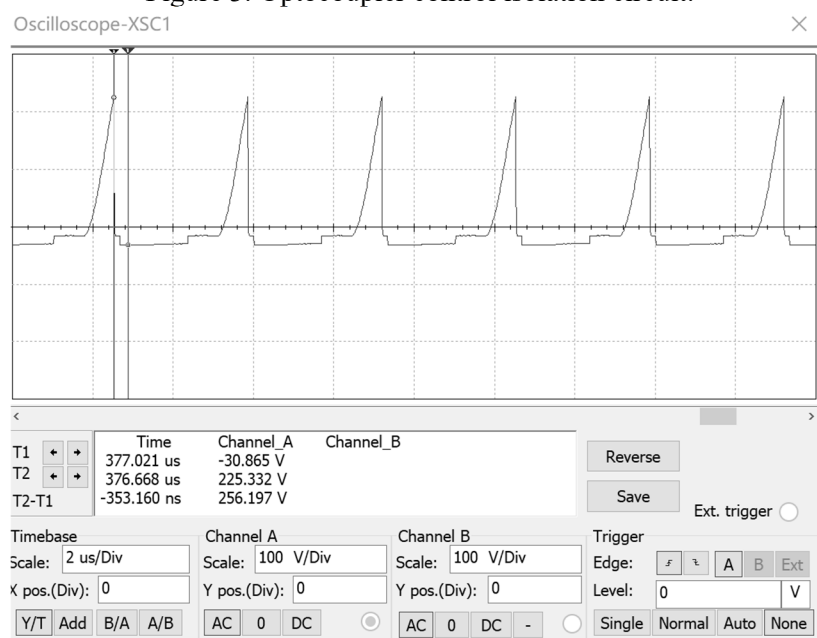


Figure 4. The simulation waveform.

4. Design of ultrasonic receiving circuit

As the ultrasonic signal propagates in the medium, it will be attenuated. On the one hand, if the distance between the ultrasonic transducer and the reflecting surface is different, the echo signal strength will be different. Therefore, an amplifying circuit is required to amplify the echo signal to a large enough amplitude for the single-chip microcomputer to detect the echo signal. On the other hand, since there are more interference noises in some harsh environments, it is necessary to filter the echo signal with a filter to obtain a signal in the frequency range. After the preamplifier circuit, filter circuit and variable gain amplifying circuit, the ultrasonic echo signal of suitable size and amplitude can be extracted and sent to the single-chip microcomputer for detection and sampling processing.

4.1. Preamplifier circuit

If the echo signal is not processed, an echo signal of only tens of millivolts and doped with noise of different frequencies will generally be received. Therefore, amplifying the weak echo signal in the receiving circuit is the primary task. The operational amplifier selected in the preamplifier circuit is AD8610AR, which has the characteristics of high speed and low power consumption, and the gain

bandwidth product is 25MHz, which is sufficient to meet the experimental requirements. The realization scheme is shown as in Figure 5. Among them, capacitors have the function of blocking DC and through AC, which can effectively prevent the direct current signal from entering the receiving circuit. Two diodes in opposite directions and connected in parallel can prevent excessive noise signals or echo signals from entering the receiving circuit and causing damage to the echo circuit. The amplifier circuit introduces negative feedback, which makes the system run more stable. The

magnification is:

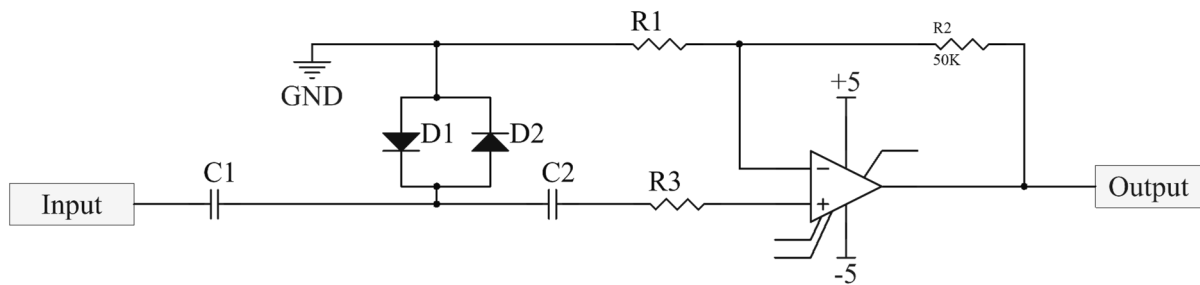
$$|A_u| = \frac{R_2}{R_1}$$


Figure 5. Preamplifier circuit.

4.2. Butterworth filter circuit

Since the ultrasonic echo signal will be doped with noise of different frequencies, the filter circuit is very important in the echo signal receiving circuit. This paper designs a sixth-order Butterworth band-pass filter circuit with a center frequency of 300KHz and a passband width of 160KHz. When the input signal is 300KHz, the signal is almost without distortion. The specific circuit design of the band-pass filter is shown in Figure 6. The three operational amplifiers used in the circuit are AD8610AR. The advantages of this operational amplifier have been explained in the introduction of the preamplifier circuit, so I will not repeat it.

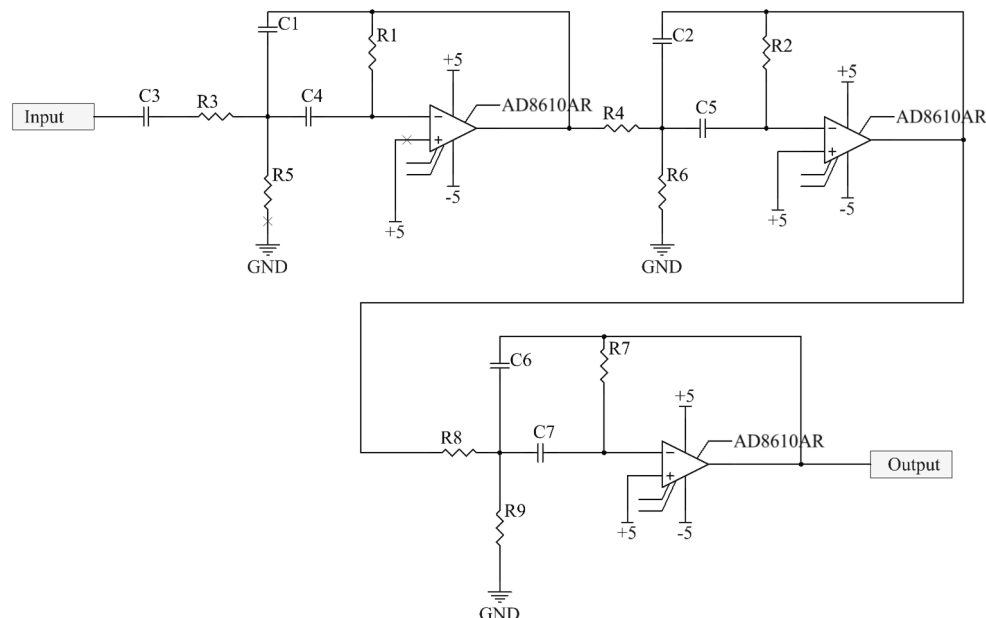


Figure 6. Butterworth filter circuit.

Figures 7 and 8 show the signal waveform with noise and the filtered signal waveform, respectively. It can be seen from figures that the filter has good frequency selection characteristics.

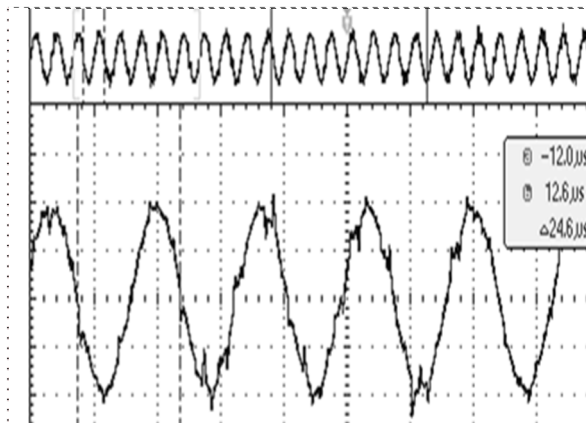


Figure 7. The signal waveform with noise.

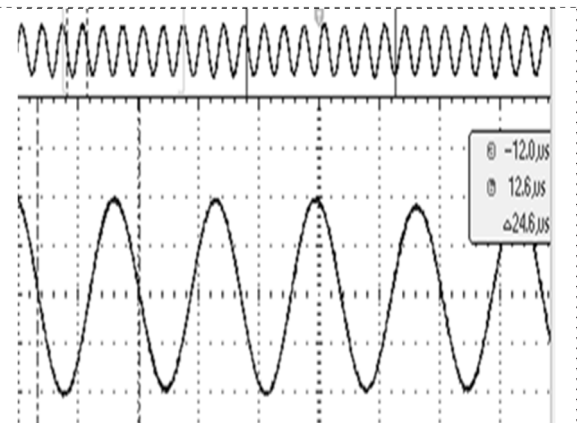


Figure 8. The filtered signal waveform.

4.3. Variable gain circuit

Due to the influence of distance, propagation medium and other factors, the amplitude of ultrasonic echo signals is not the same. If a fixed multiple of the amplifier is used, the echo amplitude will be too large or too small. Therefore, it is necessary to design a variable gain circuit to control the amplitude of the echo signal. This text chooses the operational amplifier AD8336 to realize the design of the variable gain circuit, and the concrete realization method is shown as in Figure 10. The small signal bandwidth of the operational amplifier AD8336 is 115MHz, and the gain range is 60dB. It has the characteristics of low noise, low power and high speed. It can fully meet the experimental requirements. Since the operational amplifier is a voltage-controlled operational amplifier, the gain voltage is controlled by STM32. In the experiment, 3 gears are designed to correspond to 3 different magnifications.

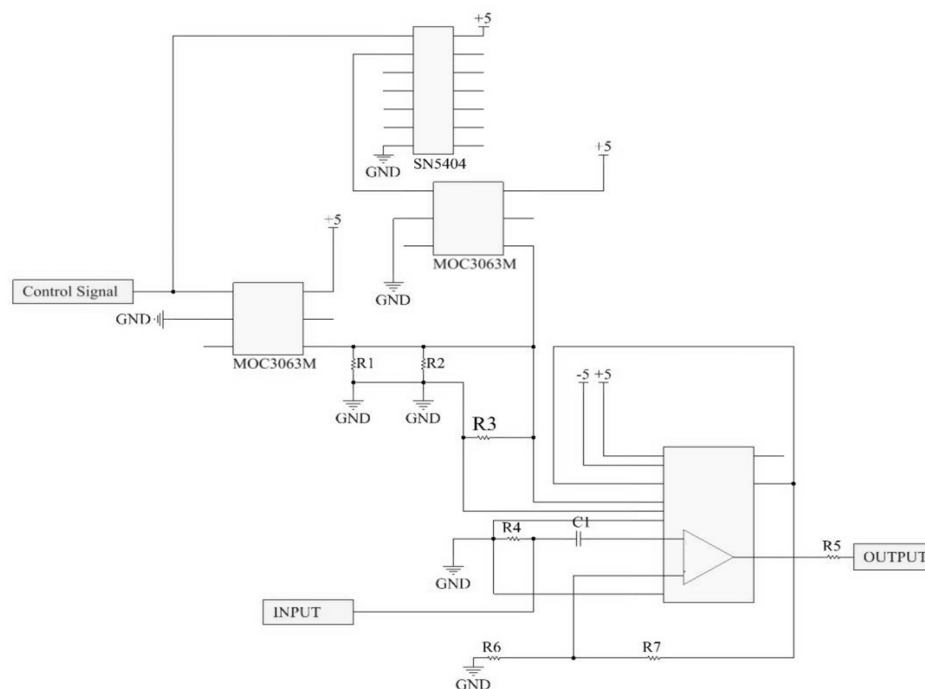


Figure 9. The filtered signal waveform.

5. Conclusion

The echo waveform is shown in Figure 11. It can be seen from the figure that the noise of the ultrasonic echo signal is relatively small. The ultrasonic ranging system uses STM429 as the control core. The digital control method has the characteristics of simple structure and convenient control; each module of the circuit is independently designed and adopts an optocoupler isolation circuit, which has the characteristics of simple debugging, clear signal and low noise. Experimental tests show that the transmitting and receiving circuits have good and stable performance, simple structure, strong anti-interference ability, and strong practicability.

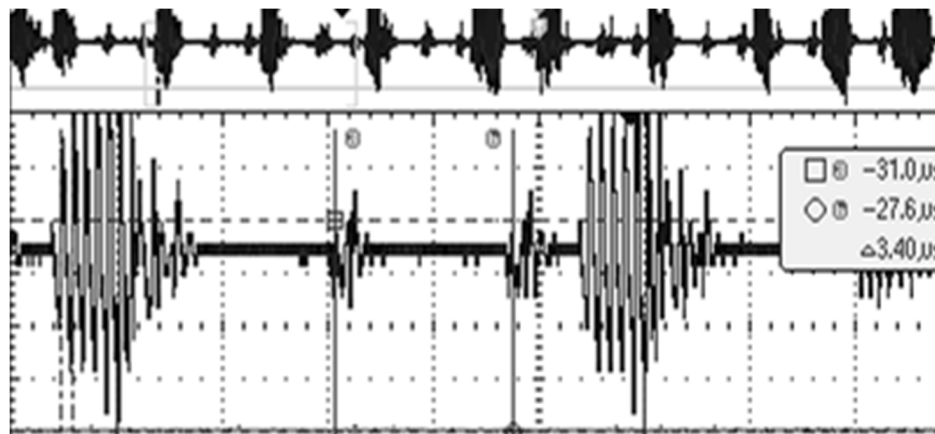


Figure 10. The echo waveform.

Acknowledgments

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