The Design of Acoustic Directional Transmitter Based on Ultrasonic Modulation

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Abstract: Directional propagation of acoustic waves based on ultrasonic modulation is a hot research topic in recent years. Through the study of the principle of acoustic directional emission, a complete set of acoustic directional transmitters was constructed using specific circuits and devices. After testing, a clear sound orientation effect was obtained. Therefore, designing and researching high-intensity, high-stability acoustic directional emitters is the key to this paper.

1. Introduction

The frequency of the sound wave is linearly moved to a higher frequency to form a modulated ultrasonic wave. The propagation characteristics of ultrasonic waves in the air have much in common with the propagation characteristics of sound in the air, but the wavelength of the ultrasonic waves is much shorter, so that the size of the sounder can be made small, and the effect of directional transmission of ultrasonic waves can be achieved. Ultrasonic waves carrying sound can achieve the effect of directional emission.

Acoustic directional launch technology has a very broad application prospect, but also has a strong commercial value. It can be used in public security and military fields, and the sound pressure level is high enough. It is a new type of acoustic weapon. The powerful sound energy emitted will cause physical damage to the enemy and cause great psychological fear. If used in anti-terrorist operations, it can effectively combat terrorists while ensuring that hostages are not harmed [1,2]. The virtual sound source effect of the directional sound source can be used to disturb the enemy's judgment. The ghostly sound can be used to combat the enemy's anger, and the enemy soldiers are exhausted and lose their will to fight. It can also be used in the commercial field. Because of the strong directivity of the sound it emits, you can use this to generate a voice for the individual without disturbing others. For example, when a visitor in a museum stands in front of an exhibit, he will only hear the sound associated with the exhibit, and will not be upset by the sound of other exhibits; guests dining in the restaurant can choose your own background music without disturbing other people; when you go to the supermarket, you will hear different products through different shelves, and customers in other places will not be disturbed by these sounds. In addition, it can also be applied to airport bird repellent equipment, which not only prevents the occurrence of "bird collision" incidents that threaten safe flight, but also protects birds well and makes the airport move closer to ecological civilization in repelling birds.

The existing directional speaker equipment basically adopts a sound hood implementation. The sound collecting hood is based on the optical principle, and the directional sound is not effective, and the sound leakage phenomenon is more serious. This paper is based on the principle of modulation and the superposition principle of mechanical waves, which makes the space occupied by sound less and effective, which makes rational use of time resources and saves space resources.

2. Research content and process

2.1 The principle of directional transmitter

Acoustic waves have many similarities with other waves. The directionality of a wave depends on the ratio of the wavelength of the wave to the size of the wave source. When the wavelength of the wave is much larger than the size of the wave source, the wave has no directionality[3]. When the wavelength of the wave is close to the size of the sound source, the directional propagation of the wave appears. When the wavelength of the wave is much smaller than the size of the wave source, the directionality of the wave becomes stronger and stronger[4].

The main frequency components of sound waves are concentrated in 300~3KHz, taking the lower frequency f1=300Hz as an example, The wavelength $\lambda 1=V/f1$, where V is the propagation speed of sound waves in air is about 340m/s, then $\lambda 1=1.13m$, the higher frequency f2 = 3KHz, the wavelength $\lambda 2 = V / f2 = 0.11m$. It can be seen that the low frequency component of the sound wave requires a larger sound source (reflection) area. For the minimum diameter of the reflecting surface of $\lambda 1$ of 1.13m, the diameter of the reflecting surface should be more than 10m to obtain a better orientation effect, which is theoretically feasible, but the theoretical value is not high.

The frequency of the acoustic wave is linearly shifted to a higher frequency to form a modulated ultrasonic wave. At the same time when the modulated wave is transmitted, a set of unmodulated signals of the same frequency carrier is transmitted. Because the air propagates non-linearly to the ultrasonic wave, due to the non-linear propagation of air to the ultrasonic wave, the two signals will interact in space and produce many “harmonic“ and “differential“ signals. One of the variance signals is the modulation signal-the sound signal, which can be heard directly. This process is called self-demodulation of the sound signal.

Firstly, the signal is modulated by the double-sideband modulator with suppressed carrier wave to the ultrasonic carrier signal, and then sent to the ultrasonic power amplifier for amplification and sent to the ultrasonic transducer array for conversion to ultrasonic transmission to the space. The other signal is the direct conversion of ultrasonic electrical signals into ultrasonic waves and transmission into space. The block diagram shown in Fig.1:

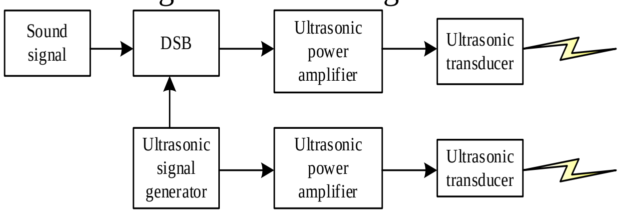


Fig.1 Block diagram of principle of acoustic directional transmitter

2.2 The experimental process

In order to make the emitted sound signal directional, the sound signal must be modulated to the frequency of the ultrasonic wave. The modulation method suiTable for self-demodulation in the air is only the amplitude modulation, the efficiency of the conventional amplitude modulation is too low, Although the single-sideband modulation saves bandwidth and saves transmit power, its circuit structure is complex. Therefore, the DSB-SC modulation method is selected. The circuit is relatively simple, and a complete audio signal can be recovered by self-demodulation in the air. The carrier signal in the modulation is suppressed by means of balance and cancellation. This article chooses the analog multiplier MC1496 as the core component of the ultrasonic modulator. Analog Multiplier MC1496 is an active nonlinear device that enables the multiplication of two analog signals (voltage or current), that is, the output signal is proportional to the product of the two input signals. The circuit diagram of the DSB-SC amplitude modulator using the MC1496 is shown in Fig.2.

As an analog multiplier, MC1496 has a variety of amplitude modulation and demodulation functions [3][4]. Signal modulation is mainly realized by addition and multiplication. The addition method realizes the offset of the modulation signal and multiply realizes the amplitude modulation. The MC1494 is powered by dual power supplies (+12V/-8V). It is designed to suppress the carrier sideband amplitude modulator in Fig.2, and to amplify the modulated signal to the desired signal level of the ultrasonic power amplifier through the adaptation circuit. Pin 5 is grounded through a bias resistor. The carrier signal is generated by the ultrasonic signal generator and coupled to the pin 10 through the C1 high frequency coupling capacitor. The pin 8 is grounded through a high frequency bypass capacitor C2, and the pin 10 and the pin 8 together form a differential input end of the carrier signal. The modulated signal is low-pass filtered and then loaded to pin 1, pin 1 and pin 4 together form the differential input of the modulated signal (audio signal), and 1KΩ of the negative feedback resistor is connected between pin 2 and pin 3, mainly It is to extend the linear dynamic range of the modulated signal, and the larger the resistance value, the larger the dynamic range, but the gain of the multiplier is reduced. The resistor and varistor between pin 1 and pin 4 form a balance adjustment circuit. By changing the resistance of the varistor, the modulation factor can be changed. W1 is the balance adjustment. By adjusting W1, the effect of suppressing the carrier can be achieved. W2 and W3 are input level adjustments. W4 is the adaptation adjustment so that the output average level of the adaptation circuit meets the requirements of the ultrasonic power amplifier.

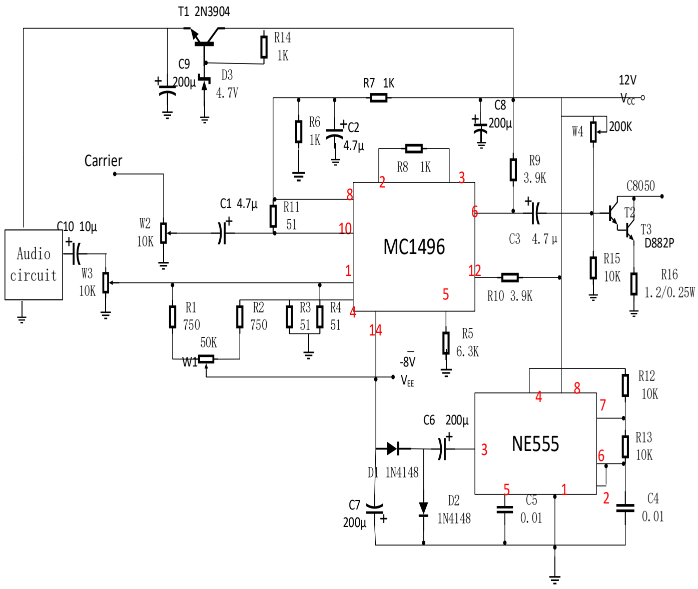
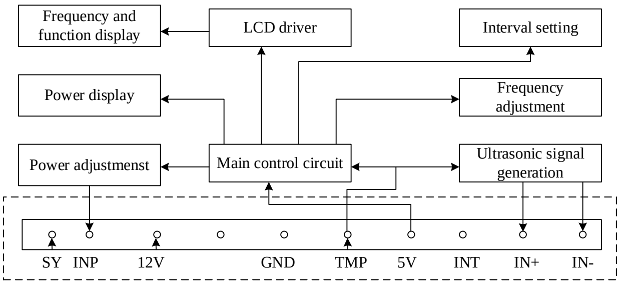


Fig.2 DSB-SC amplitude modulator based on the MC1496

The higher the frequency, the greater the attenuation in the air, but the higher the frequency, the better the directionality, so we choose the frequency adjusTable signal generator in the generator of the ultrasonic signal to facilitate the selection of the best ultrasonic frequency in debugging.

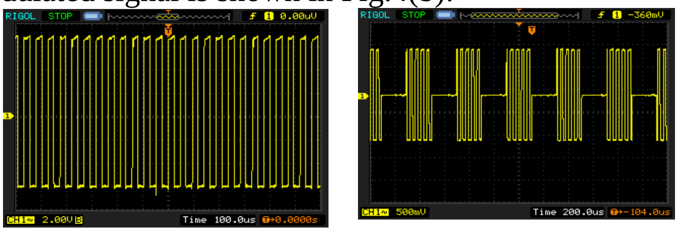
The schematic diagram of the ultrasonic signal generation is shown in Fig.3. The main control circuit completes the control of the whole circuit and the supervision of the working state; the frequency and function display part shows the current working frequency band, and the fault display fault code appears. The power display uses a ten-segment LED to proportionally display the output power of the amplifier. The power adjustment adjusts the output power and has a memory function. Set the emission time and intermittent time of the amplifier when the interval is set. The frequency adjustment is divided into two levels. One is the four-position dial switch for large frequency setting of 20KHz~90KHz, and the other is to adjust the internal frequency of the section by potentiometer, each step is 1KHz. The ultrasonic signal generating circuit generates the ultrasonic signals required for the experiment under the control of the main control circuit and the frequency adjustment. The interface between the ultrasonic signal and the power amplifier includes IN- and IN+, which are the reverse signal and the forward signal of the ultrasonic signal, respectively. When the forward signal is fed back to the ultrasonic signal generating circuit via the feedback control terminal TMP, the ultrasonic signal generator stops working. The frequency is displayed as "00" KHz. INP is the power control signal output. It is a 20 kHz intermittent signal with intermittent time Tj=10ms (100Hz). The duration of the signal determines the output power.



Interface with amplifier

Fig.3 The schematic diagram of the ultrasonic signal generation

The frequency of the ultrasonic signal used in this article is 21KHz. The input carrier is a 20KHz square wave signal which is shown in Fig4(a):, and the audio frequency is a 1KHz square wave signal. The obtained modulated signal is shown in Fig.4(b):



(a)20kHz carrier signal

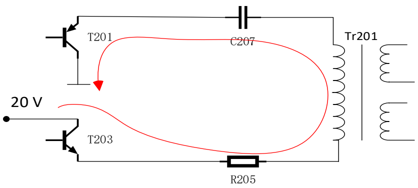
(b)21kHz modulated ultrasonic signal

Fig.4 Waveforms of Ultrasound Signals

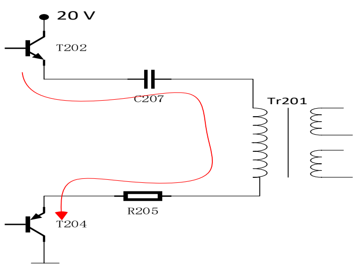
The ultrasonic power amplifying circuit is mainly composed of a power amplifier driving circuit and a power amplifier final stage amplifying circuit. The power amplifier drive circuit is shown in Fig.5, and the power amplifier final stage amplifier circuit is shown in Figure 6:

Amplifier drive circuit: The 21kHz ultrasonic signal outputted by the signal generator portion of Fig. 2 is input from the forward drive end of the IN+ input power amplifier, inverted by the inverter, and input from the IN- to the reverse drive end of the power amplifier.

T201 and T202 form the reverse drive end, and T203 and T204 form the forward drive end. The positive half cycle T203 of the signal is turned on, T204 is turned off, T201 is turned on, T202 is turned off, and a current signal is formed at the primary of the transformer Tr201 as shown in Fig. 5(a),the negative half cycle T203 of the signal is turned off T204 is turned on, T201 is turned off T202 is turned on, and the current signal is formed at the primary of the transformer Tr201 as shown in Fig.5(b):



（a）Positive half cycle conduction circuit



(b)Negative half cycle conduction circuit

Fig.5 The power amplifier drive circuit

It can be seen that the corresponding alternating current is formed at the primary of Tr201 in the positive and negative half-axis period of the signal, and sufficient driving power is provided for the final stage of the power amplifier.

The working principle of the final stage of the power amplifier: the final stage of the power amplifier consists of u101 and u104. The principle circuit is shown in Figure 9. The Tr201 has two windings in the secondary, the power amplifier u101 is connected to the same name, the u104 is connected to another group of different names, the output out A and the output out B are connected to the output transformer Trout. The positive half cycle u101 of the signal is turned on, u104 is turned off, and the current flow direction is V→u101→ out A→Trout primary→c106. The negative half cycle u101 of the signal is turned off by u104, and the current flow direction is V→c107→out B→Trout primary→u104. U101 and u104 are both high-power MOS tubes, which can form a large excitation current at the primary of Trout. The change of this current is the same as the ultrasonic signal change, and the power amplification of the ultrasonic signal is completed. U101 and u104 can use multiple power tubes directly to achieve greater power amplification. This is also the biggest advantage of this power amplifier circuit design.

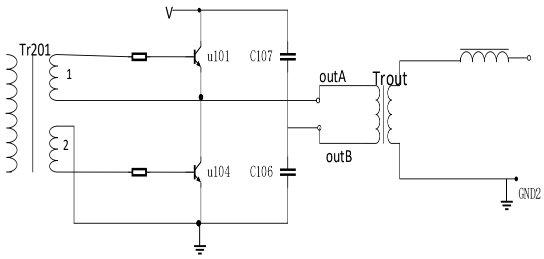


Fig.6 The power amplifier final stage amplifier circuit

The acoustic directional transmitter is mainly composed of a host, an auxiliary machine and a transducer. The host completes the ultrasonic modulation, and the auxiliary machine achieves power amplification. The transducer converts the self-demodulated two-way ultrasonic electric signals into ultrasonic waves and transmits them to the space. The physical object is shown in Fig.7.

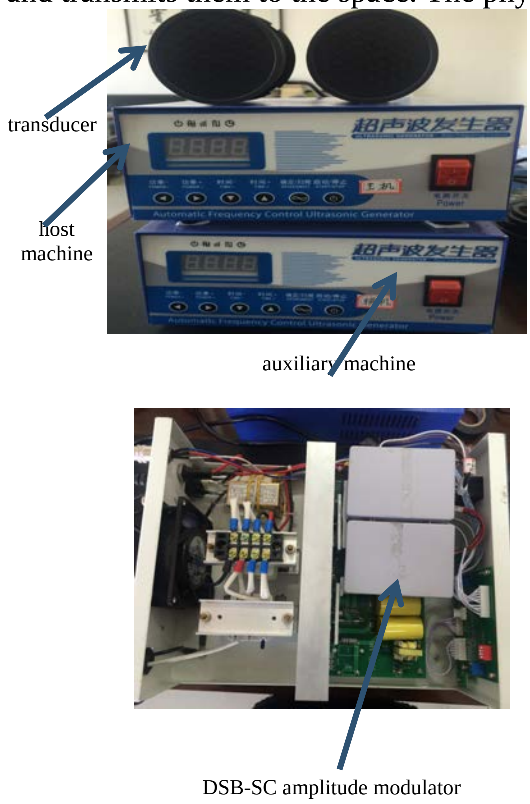


Fig.7 Physical object of acoustic directional transmitter

2.3 The experimental results

The actual test environment is an outdoor open space, and there is a need to satisfy the requirement that the direction of sound propagation is not obstructed. The test site diagram is shown in Fig.8.The purpose of the test is to determine the directional effect of the sound and to test the divergence angle of the sound wave. The test method adopts human hearing as a receiving standard, and emits a directional sound wave in an outdoor open space. The tester receives the sound according to the transmission distance and tests the divergence angle.

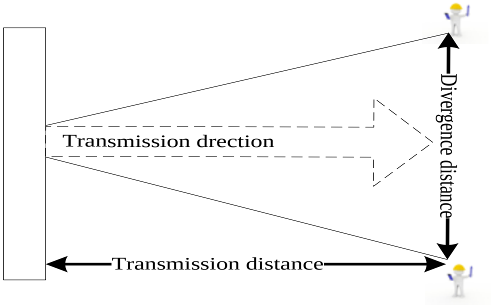


Fig.8 Test site schematic

2.4 Actual test results

(1) Under the condition that the transmission power is 100W, the divergence distance of the sound at a distance of 10m from the transmission distance is 5m, the divergence angle is 30°, and the reception sound is clear.

(2) Under the condition of transmission power of 100W, the divergence distance of the sound at a distance of 30m from the transmission distance is 6 m, the divergence angle is 15°, and the received sound is basically audible.

(3) Under the condition of transmitting power of 300W, the divergence distance of the sound at a distance of 30m from the transmission distance is 6m, the divergence angle is 10°, and the received sound is basically audible.

Within the receivable distance, the intensity distribution of the sound is relatively uniform, and there is no obvious near-strong and far-weak feature. Conforms to the principle of demodulation and transmission of two acoustic waves in a nonlinear space.

Test conclusion: The sound wave direct transmission device has obvious sound wave directional emission characteristics. The divergence angle is less than 20°.

3. Conclusions

Due to the nonlinear effect of the ultrasonic wave in the air, the audible sound wave can only be obtained in front of the directional transmitter. After the ultrasonic directional transmitter designed in this article has undergone a series of circuit design and actual debugging, the effect of sound-directed transmission reaches a more satisfactory level of orientation. Normal audio signals can be heard in the direction of the acoustic directional generator, while only very weak acoustic signals can be heard in other directions.

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