Unidirectional Parametric Speaker

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Abstract: One of the most significant ways that people convey information is through sound. The production of directed sound is dramatically increasing in terms of personal privacy in contemporary culture. The Ultrasonic Unidirectional Speaker project aims to design and develop a compact, lightweight, and energy-efficient speaker system that can deliver sound in a specific direction using ultrasonic waves. The system utilises the non-linear properties of air to generate audible sound waves through the use of ultrasonic frequencies, creating a directional sound beam that can be precisely targeted. The work involves designing and fabricating the necessary electronic components, such as the ultrasonic transducer, amplifier, and signal generator, and developing software to control the system. The ultimate goal of this project is to create a high-quality directional speaker system that can be used in a variety of applications, such as public address systems, directional sound for displays, and immersive gaming experiences.

1 Introduction

The parametric array idea, which Westervelt developed and described in 1960 at an Acoustical Society of America meeting, serves as the foundation for the basic theory of a parametric loudspeaker. Bennett and Blackstock demonstrated in 1975 that a parametric speaker may function using air as the transfer medium by directing collimated beams at frequencies of 18.6 kHz and 23.6 kHz and measuring the 5 kHz difference frequency wave.

The field of audio technology has seen significant advancements in recent years, with various research efforts being focused on improving the quality, efficiency, and directional accuracy of audio systems. One such innovation in this field is the development of ultrasonic unidirectional speakers, which utilize ultrasonic frequencies to create directional sound beams. The use of ultrasonic waves in audio technology has

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been explored extensively due to its potential for energy-efficient and high-quality sound delivery. The ultrasonic unidirectional speaker system works by emitting ultrasonic waves, which interact with the air molecules to create audible sound waves that are directional and focused. This technology has significant potential in applications where targeted audio delivery is required, such as public address systems, displays, and gaming experiences. This research paper presents the design and development of an ultrasonic unidirectional speaker system, including its electronic components, control software, and testing. The results of this study demonstrate the feasibility and potential of ultrasonic unidirectional speakers in various audio applications, highlighting their advantages over conventional audio systems.

2 Literature Survey

Several publications were thoroughly surveyed, and their benefits and drawbacks were examined and analysed. Here are a few of the observations:

During the analysis, it was studied that Small piezoelectric transducers, which typically comprise piezoelectric boards and radial cones, are the major topic of this research study. The authors suggest a brand-new design that produces two resonant peaks that may be tuned to produce the optimal frequency response for parametric speakers utilizing a uni-morph diaphragm and a flat metal plate. A better transducer has been created by them that meets the optimal frequency response for parametric speakers using theoretical analysis[1]. It has been reported how to create an ultrasonic transducer for parametric speakers that could enhance mid-range audible noises. The junction coefficient and phase difference of two input signals is controlled to create the transducer's two linked diaphragms' close resonant frequencies and improved resonant peaks. The theoretical considerations and design points used to create the prototype transducer and verify its characteristics through FEM simulations and experiments[2]. For extremely directed speakers in air environments using parametric array transducers, a new power amplifier and power supply have been proposed. The system applies the envelope tracking technique and makes use of a push-pull class B-type amplifier for high linearity and a DC-DC converter-type power supply for high efficiency and energy recovery[3].A parametric speaker system with 144 ultrasonic transducer elements and FPGA signal controllers has been created for enabling electrical control of the direction of the audible sound wave with a resolution of 2° and a range of 15°. Using 12-bit data and ring buffers, the device could attain a temporal resolution of 1 s. With the rectification of input direction data, control of up to 20° is feasible[4].The design and analysis of a parametric speaker system that operated in a non-linear environment with amplitude-modulated ultrasonic waves and automatic demodulation. The system consists of 50 ultrasonic acoustic transducers with a 40 kHz resonance frequency and a digital component for amplitude modulation and signal processing. The effects of several AM methods on total harmonic distortion (THD) were contrasted, and measurements of the parametric speaker's radiation characteristics were made. Mathematical tools for defining the propagation of a parametric sound beam through a non-linear medium, along with a theoretical definition of parametric acoustics were also included[5].

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A sound concentrating approach based on parametric effect was implemented for employing two kinds of ultrasonic speakers to transmit ultrasound as a carrier and audible sound as ultrasound by balanced modulation. Beat signal amplitude modulation is caused by the intersection of the two ultrasonic waves, and the parametric effect is used to demodulate audible sound in the atmosphere. This makes it possible to concentrate on the audible sound so that only those nearby the intersecting point can hear it[6].The development of small, premium parametric speakers for audio communication with privacy protection was explored. The speakers use modulated ultrasonics to produce audible sounds that are narrowly directed.Enhancement of electroacoustic efficiency and expansion of accessible bandwidth, as well as optimization of transmitter circuits and modulation techniques based on transducer parameters, were focused on[7].To create a compact, multi-transducer parametric speaker unit there are many techniques were utilised. The created transducer consists of radial cones and double-linked diaphragms in addition to the looped horn, a sonic crystal waveguide. These parts enable the parametric speaker unit to produce ultrasonic waves with high sound pressure levels and restricted directivities. The performance of the four-transducer parametric speaker unit is examined mathematically and experimentally in this paper. A few transducers can be utilised to create similar units using the ultrasonic transducer's findings and design specifications[8]. It investigated how powerful amplitude-modulated (AM) ultrasonic waves interact nonlinearly to produce directional audible sound, particularly in the context of sound reproduction using a parametric speaker. To adjust the sidelobe level of the beam pattern, A unique approach makes use of array signal processing techniques and acoustic nonlinearity was suggested. Additionally, A single sideband modulation (SSB) scheme is created for audio signal transmission that enables constant beamwidth beamforming by varying the weightings of the carrier and sideband frequencies. The design of a broadband beamformer is further examined in this work, and simulation tests are used to confirm its efficacy[9].A novel method of human-humanoid communication has been examined that uses a directional speaker that emits directional sound beams using the intermodulation of ultrasonic sound beams and nonlinearity in air. The technology fixes the issue where the humanoid cannot understand human speech while speaking and enables the humanoid to whisper to a specific individual. The effectiveness of the directional speaker to carry out these functions is demonstrated by preliminary trials. The communication technology also enables sound production inside a limited space, enabling whispering and enhancing security. The method has the potential to lead to the creation of fresh, sophisticated human-humanoid communication in the future[10].The performance of the speaker in the near field was examined, and measurements of its directivity and attenuation characteristics were made. The speaker exhibited a very directed pattern, according to the study, although its beamwidth was broader than expected in the audible sound range. According to the article, the speaker's use may be constrained in the near field, and modifications may be necessary to enhance its performance[11].

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3 Methodology/ Experimental

3.1 Structural Outline

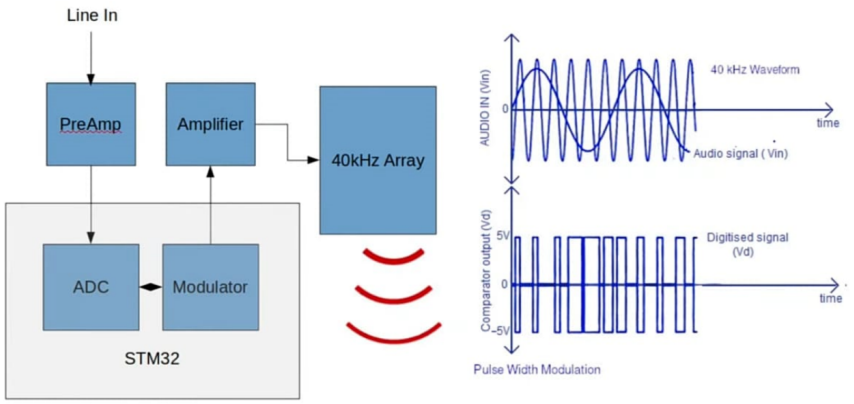

Fig. 1. Block diagram

3.2 Implementation Details:

The first section consists of building a transducer array to emit the ultrasonic sound waves which propagate in a linear direction. The second section consists of image processing for detecting human faces and pointing the transducers in the direction of the detected face.

1. Parametric Speaker:

A drive circuit, a transducer array, and an audio source make up the Parametric Speaker (phone, radio, computer, etc.). The audio source is modified with a 40 kHz carrier input before being sent into the driving circuit. It is transmitted to the transducer array after being amplified. The input audio signal was separately amplified depending on the source. By employing a waveform generator that can modulate a signal, the drive circuit was built. This waveform generator's output was amplified even more. A typical PA amplifier can be used to accomplish this (70 V). Any tiny, low-distortion voltage amplifier can be used to amplify the audio signal, should that be necessary. The simple drive circuit required four elements to construct.

1. A modulator: In order to modulate the carrier signal a simple circuit was designed using IC555.

2. An H-Bridge: It helped to disconnect the inductive load from the modulating chip by using IC L293.

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3. The amplifier: It is possible to achieve this with two IRF540 MOSFETs.

4. A 24V power supply: It is possible to construct this from scratch, but it is quicker and simpler to buy or locate a power supply.

The driving circuit diagram is provided below. Different modulation methods produce different levels of total harmonic distortion (THD). A valid generalisation is that THD decreases with increasing modulation technique complexity. PWM, which has a high THD but is the easiest to prototype, is the result. Additional types of modulation include recursive single sideband AM, root square AM, and basic double sideband AM, listed from greater THD to less. Phase modulation performs the best among the frequency modulation techniques, while FM, like PWM, operates but can produce distortion. Preprocessing can be used to reduce some distortions and improve the sound, but it is very complicated. If desired, this can be accomplished with a quick microcontroller or a good programmable audio chip like the Adau1701.

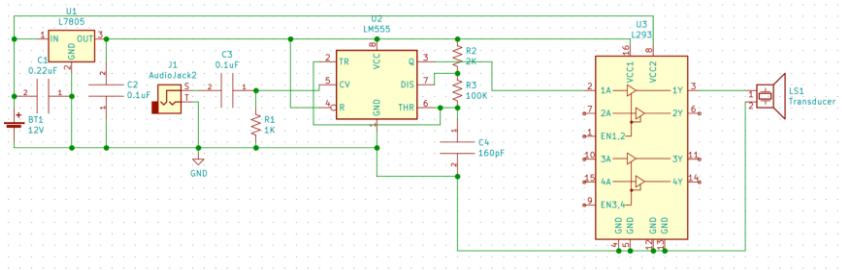

Fig. 2. Driver Circuit using IC555

Components Required:

1. L7805
2. IC LM555
3. IC L293
4. Filtering Capacitors
5. Resistors

The above circuit can be divided into four parts, the first part of the circuit is the voltage regulator which steps down the 12V to 5V. The audio jack is connected to input the audio signals from the source. Capacitors are used to filter out the noise in these audio signals. Next, these audio signals are fed into the IC 555 as the modulating signals. The carrier signals are modulated with the modulating signals and are passed further to IC L293 for amplification. Finally, the signals are fed into the array of ultrasonic transducers to generate a linear sound wave.

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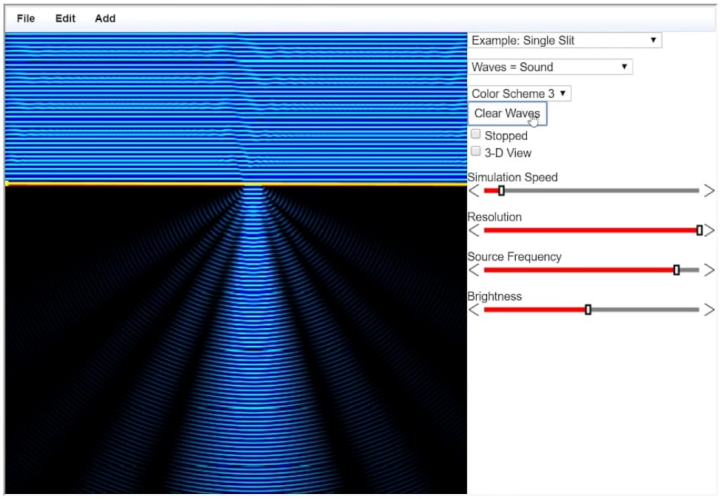

Fig. 3. Ultrasonic waves linear dispersion

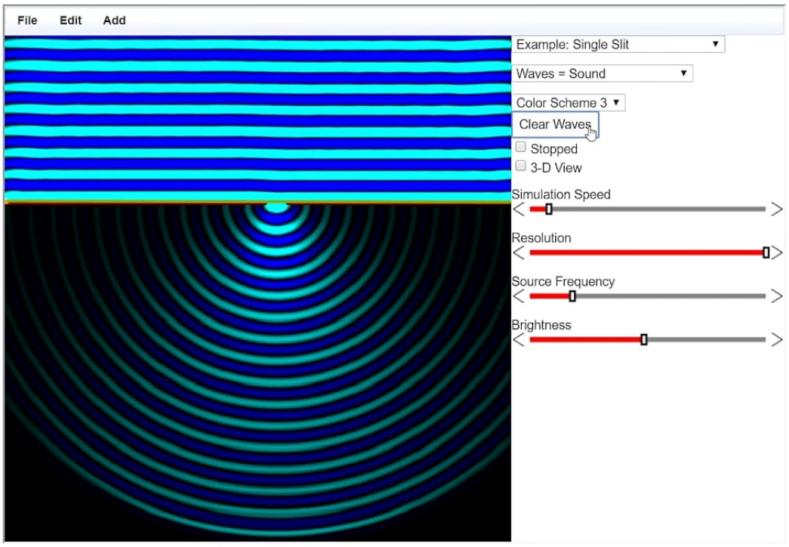

Fig. 4. Audible frequency range sound dispersion

1. Face recognition system

The face recognition system has a web camera that uses image processing to identify human faces and instructs the servos to point the transducers in the subject's direction. With input from a camera, the initial step is to snap an image. Each frame of the live video is converted into a separate image. The system then uses the Dlib library to detect or locate the face, and afterward, it predicts the landmarks of significant parts of the discovered face. The ear landmarks are utilized to find faces after the landmarks are anticipated.

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To determine the precise location of the 68-(x,y) coordinates that correspond to the facial structure of the face, the pre-trained facial landmark detector found inside the dlib package is employed. The main facial features represented by these 68-(x,y) coordinates include the ear, mouth, left and right eyebrows, left and right eyes, nose, and jaw. The only relevant (x,y) coordinates are those of the left and right ears. These coordinates of the ears are then used to align the speakers in the direction of the subject standing in front of the camera.

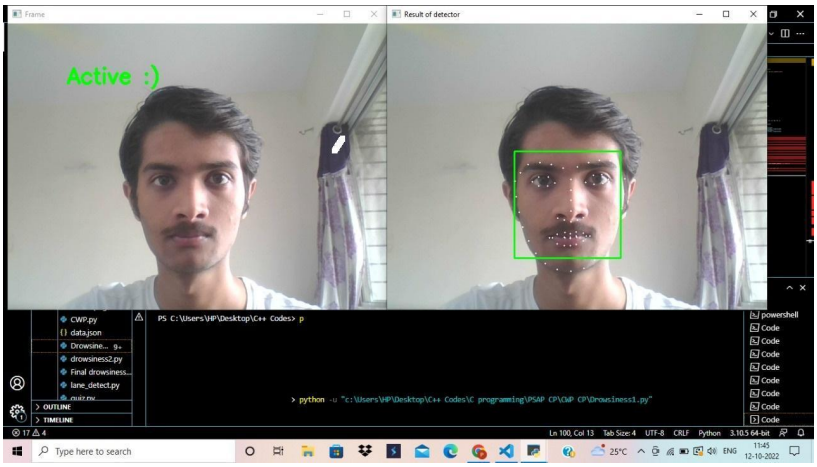

Fig. 4. Face detection

4 Results and Discussion

The results demonstrate that the unidirectional parametric speaker is a type of audio technology that produces a focused, directional beam of sound using ultrasonic waves.
In order to analyze the waves generated by the circuit, a Digital Storage Oscilloscope (DSO) was used. It measured the frequency of the modulated and carrier signals and their amplitude (in volts).
Following is the output displayed on the DSO:

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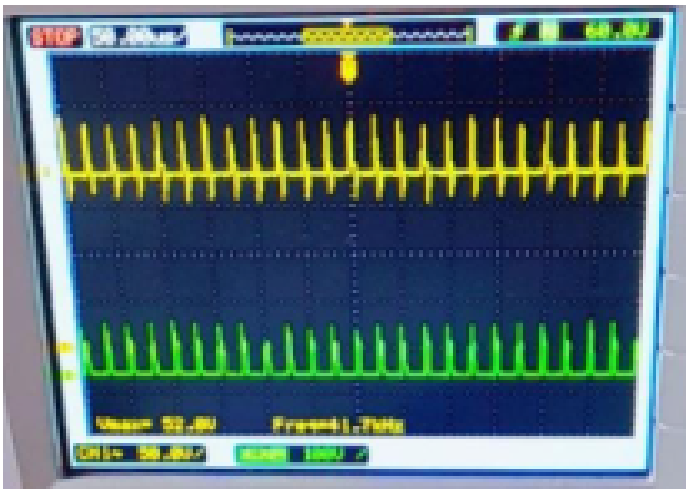

Fig. 4. DSO Output

The yellow waves represent the output modulated signal, while the green wave represents the carrier signal.
The carrier wave was found to have a frequency of 40 kHz, hence the outcomes were as anticipated.

The capacity of this technology to deliver audio without the use of conventional speakers and to target particular locations or people without disturbing neighbouring people has been drawing interest in recent years. When it's crucial to provide focused audio messages in crowded spaces, unidirectional parametric speakers may be a helpful tool. Unidirectional parametric speakers may be especially useful in applications like public address systems in busy public spaces, museum exhibits with multiple audio displays, and point-of-sale advertising in noisy retail environments because they lessen ambient noise pollution and concentrate the sound in a particular direction. The potential uses for unidirectional parametric speakers include areas like point-of-sale advertising, museum exhibits, public address systems, and entertainment. A promising new technology has been identified for conveying high-quality audio messages in difficult acoustic settings. Additional investigation is required to examine the potential uses and restrictions of this technology as well as to create fresh strategies for enhancing its functionality in various contexts.

5 Conclusion

By research into the parametric array in the air, a fascinating and challenging method of manufacturing directed sound has been created. Unlike traditional loudspeakers, which emit sound waves in all directions and need a big array to produce a focused sound, parametric loudspeakers have numerous advantageous properties that enable excellent directivity, a customizable beam, and a reasonable implementation size. Although a parametric loudspeaker's bass quality is unsatisfactory for reproducing music, it is predicted that psychoacoustics technology will be able to address this issue. On the other hand, as recent advancements in digital processors and ultrasonic emitters become available, more applications can benefit from the deployment of parametric loudspeakers

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and more preprocessing procedures can be performed in real-time.

6 Future Scope

There are still a lot of functionalities that could be implemented in order to make the speaker more efficient and high utility. Some of them that could be implemented in the future are:

1. Improved Sound Quality: One of the main challenges of ultrasonic unidirectional parametric speakers is achieving high-quality sound output. In the future, there may be advancements in technology to improve sound quality and enhance the overall user experience.

2. Increased Range and Directionality: Currently, the range and directionality of ultrasonic unidirectional parametric speakers is limited. Future advancements may enable these speakers to project sound over a greater distance and with more precise directionality.

3. Use in Commercial and Industrial Settings: Ultrasonic unidirectional parametric speakers have potential applications in commercial and industrial settings, such as retail stores, museums, and airports. In the future, we may see an increased use of these speakers in such environments.
   Overall, the future scope of ultrasonic unidirectional parametric speakers is promising, and we may see further advancements and applications of this technology in the years to come.

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