Infrasonic Waves
Sources, Effects, Generation and Applications

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Abstract — This paper describes the generation and applications of infrasonic waves. Lying below the audible range of acoustic waves for humans, infrasound is a type of sound wave which has seen various degrees of success in a variety of applications such as soot cleaners and leakage detection and localization of pipelines. This paper explores the sources and impact of infrasonic waves on the human body as well as the circuitry to accurately generate infrasound signals of appropriate amplitude and frequency. Also, the various applications involving these omni-directional waves and their viability are discussed including their application in the detection of natural disasters, industrial cleaning applications as well as the applications in wildlife conservation.

Index Terms—Infrasonic, generation, application, effect, amplification, implementation, sources, soundless music, power-harvesting sensors, infrasound, sub-audible. (Keywords)

I. INTRODUCTION:

Infrasonic waves are sub-audible acoustic waves which typically lie below the human hearing threshold (usually between 0.1 to 10 Hz, sometimes going up to 20Hz).While these waves cannot be "heard" by humans, with a high enough decibel output, these waves can be perceived in various parts of the body. Normally, humans can hear from a range of 20 Hz to 20 KHz. It is widely accepted that several species of animals such as the elephant can perceive and communicate over a significantly higher range; this ability to perceive certain infrasounds is theorized to be a key factor in animals' abilities to presage natural disasters. Some humans are found to be more perceptive of infrasonic waves compared to others; this is demonstrated in the Purcell Room experiment conducted in London in 2003 [2]. This paper discusses techniques to replicate/generate and detect these signals and the various applications as well as future scope for the same. An infrasound wave has the following distinct properties which discern it from other sound waves: long wavelength, omnidirectional dispersion and low absorption. Low absorption is caused by the long wavelength, as it minimizes the absorption by intervening particles as the wave passes through a medium. This allows the wave to travel though a medium with the least loss of energy.

II. SOURCES

Infrasound is created by several natural sources such as the wind, waves, earthquakes, thunderstorms and volcanoes [4]. The ocean tides, avalanches and even meteor and meteorites may act as sources for these radiations. They are produced in varying degrees of loudness by both natural as well as man-made (artificial) sources. In nature, some animals make use of infrasound for communication. These animals include mammals such as whales, elephants, lions and crocodiles. Some animals are also much more susceptible to these frequencies due to the significantly higher audible range. This is said to be the cause for their ability to "detect" and avoid natural disasters such as tsunamis [10] or volcano eruptions which are presumed to produce high-speed infrasonic waves [4].

Natural sources aside, with large-scale industrialization and technological progress, the number of artificial sources of these waves has burgeoned. Wind turbines [5], machinery [7], trains, aircrafts, chimneys, even church organs and home plumbing systems; all of these may be sources of infrasonic waves [1], [2]. In the case of wind turbines, infrasound is generated by spontaneous pressure fluctuations when the blade of the wind turbine passes through a region of lower wind velocity near a pole brace/mount. Significant amplitude waves may be generated, however, the signal is seen to be greatly affected by wind noise, making its measurement difficult.

The extent to which these sources have increased in number is alarming leading to government agencies and independent organizations carrying out research on the health effects of these non-ionizing radiations [2], [11] and [12].

III. EFFECTS ON THE HUMAN BODY

Infrasound waves having high decibel levels may have several unique effects on the human body, as seen from the table (1) below. Its effects can be seen even from the reaction of the body to naturally generated infrasound like the kind observed in a tiger's chuffle and growl and also in the sounds made by lions, crocodiles and whales. Another such example would be the feeling of unrest or uneasiness that some people experience when in some of the older churches in Britain; it is hypothesized that this feeling was caused by the harmonics in giant organ pipes, which gave rise to powerful infrasonic waves. The effects of this noise are of particular concern due to numerous sources (omnidirectional), efficient propagation, and reduced efficacy of many structures (dwellings, walls, and hearing protection) in attenuating low-frequency noise compared with other noise [1]. In industrial and neighboring areas, where the infrasonic acoustic waves are produced by machinery as a part of background noise, these waves are posited to cause a disturbance in sleep patterns. This is because during the night, lower frequencies dominate the sound spectrum. On being exposed to infrasound the body may react by activating the basic survival instincts or "Fight or Flight" response. At this point, the senses are heightened and the brain may begin to misinterpret what is being sensed. At 18 Hz, a slight resonance of the human eye is presumed to occur which gives rise to visual hallucination. To study the psychological effects of infrasonic waves, two consecutive concerts were conducted in the Purcell Room, London, on 31st May 2003. One of these concerts had infrasound (extreme bass sound, below 20 Hz in frequency) mixed into the music as an experiment [2]. A portion of the audience were observed to show symptoms or effects such as shivering, chills and slight hallucinations (22%). The effects of infrasound have been a focus of study mostly because of the nature of the wave; it can travel long distances without losing much power due to its low absorption and large wavelength and also, it can travel through most media, making its effects difficult to minimize. The long-term effects of these waves (as seen in people who reside near or work at wind turbine farms) include irritability, headaches, sluggishness, nausea and a general sense of unease. Intense infrasonic noise is observed to produce clear symptoms including respiratory impairment and aural pain. Some of the commonly documented effects of infrasonic noise are listed below:

TABLE 1: Effects posited of Infrasound on the human body

Frequency(In Hz)	Effect Posited
4	Respiratory Trouble
9-10	Nausea
17-18.9	Fear, Visual Hallucinations, chills

Other effects may include irritability, dizziness, difficulty sleeping and headaches. The effects of these waves have gradually become a cause of concern due to the possible damage they may cause to the human psyche. Potential methods of generation of these waves are discussed below.

IV. METHODS OF GENERATION

Techniques used to generate infrasound signals can be differentiated from the techniques used to generate acoustic waves in the audible spectrum by their method of actuation or process employed to actually generate the wave. The average audio voice-coil speaker system cannot be used to generate infrasonic waves because they are designed for sounds from the audible spectrum. Using these speaker systems to produce infrasonic waves would require their driver to provide excessive power which may cause severe output waveform distortion or damage the driver circuit or even the coils. Some manufacturers use a motor as a replacement of the voice coil to enhance low-frequency audio performance [3]. We will consider this actuation scheme as well as the actuation scheme which makes use of a larger speaker cone and higher power in methods of generation.

A. Wave Generation and Amplification

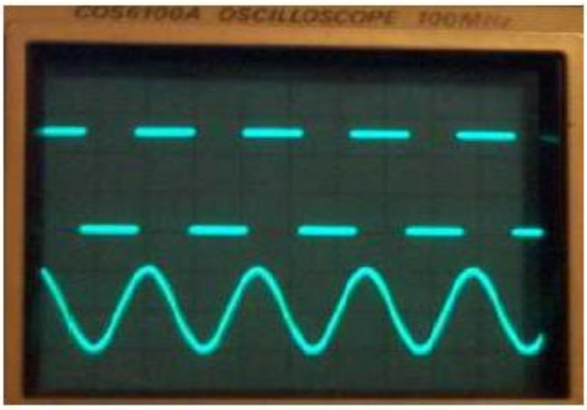

Fig 4.1 Waveforms of generated infrasonic waves.

The 555 timer IC is an integrated circuit used primarily as a timer, for pulse generation, and for oscillator applications. It can be used to provide time delays, as an oscillator. For wave generation, the NE 555 IC can be used in Astable mode in order to obtain fixed frequency square waves.

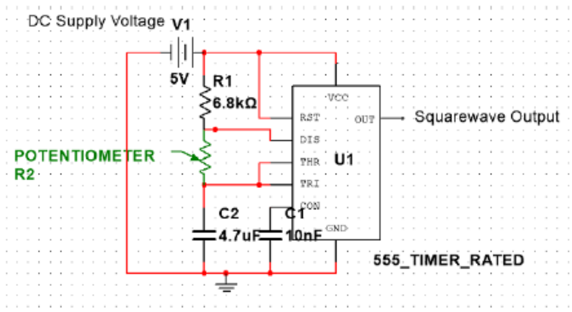

Fig 4.2 Circuit Diagram of a 555 timer configured in Astable mode

The 555 timer IC is configured in Astable mode. In this mode, the 555 timer puts out a continuous stream of rectangular pulses having a specified frequency. Resistor R1 is connected between VCC and the discharge pin (pin 7) and resistance R2 between the discharge pin (pin 7), and the trigger (pin 2) and threshold (pin 6) pins that share a common node. Hence the capacitor is charged through R1 and R2, and discharged only through R2, since pin 7 has low impedance to ground during output low intervals of the cycle, therefore discharging the capacitor. In the Astable mode, the frequency of the pulse stream depends on the values of R1, R2 and C; as seen from the formula below:

$$f=1/(\ln(2)*C*(R1+2R2)) \quad (1)$$

Where:

f = frequency in Hertz

C=capacitance in farads

R1, R2 = respective resistances in ohms

The

$$D=(R1+R2)/(R1+2R2) \quad (2)$$

Where:

D= Duty Cycle

R1, R2 = resistances in ohms

The output obtained when making use of the 555 circuit is a square wave of a particular duty cycle (which can be calculated using (2)) and frequency (1) as shown in the upper waveform of figure 4.1.

Another method of generation would involve the use of oscillators to produce a sine wave output of the required frequency. In both analog and digital domains, a variety of approaches and techniques exist to generate sine wave output. A phase shift oscillator using RC can be used in cost-sensitive applications. The transient state of the circuit is short and it has small starting and settling times. If low distortion and high precision is a requirement for the application, one can also make use of the Wein bridge oscillator circuit which is shown below.

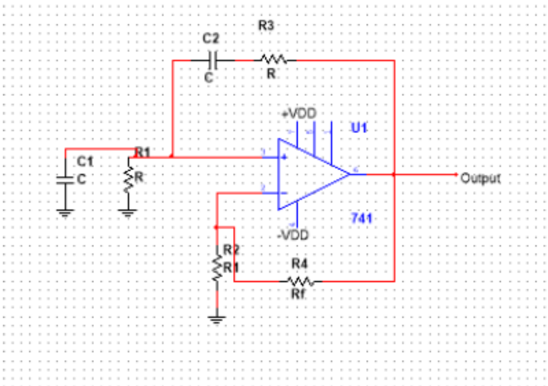

Fig. 4.2: Wein Bridge Oscillator

The Wein Bridge Oscillator is considered due to its stability and low distortion as well as the ease with which it can be tuned. The circuit involves the use of operational amplifier with feedback to both inputs. The inverting input terminal is connected to the output providing negative feedback via the resistor divider network of R2 (R1) and R4 (Rf) which allows us to control the gain of the amplifier precisely (closed loop). The non-inverting input terminal is connected to the output to provide positive feedback using the RC Wien Bridge. At the selected resonant frequency, (f) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" which leads to oscillations. For sustained oscillations, the gain of the amplifier must be selected to be greater than or equal to three. The gain is set using resistances R1 and Rf. The frequency of oscillations for the Wein bridge oscillator is given as:

$$f = 1/(2*\pi*R*C) \quad (3)$$

Where:

f= frequency of output wave in Hertz

R= Resistance in ohms

C= Capacitance in Farads

The wave generated in such a manner is not of a sufficient decibel level (irrespective of duty cycle) and must be amplified using a high fidelity audio amplifier such as the amplifier discussed below.

The amplifier we have considered is the TDA1521, which is a high gain, high fidelity amplifier. The demonstrated circuit contains few external passive components and gives 2 x 12 watt output.

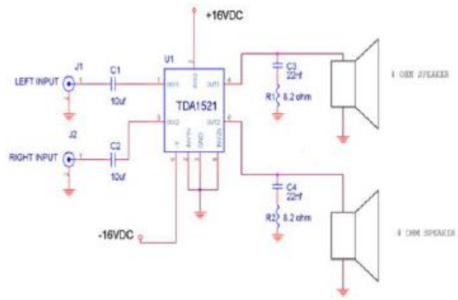

Fig. 4.3: 2-channel audio amplifier using TDA 1521

In the circuit shown above, the capacitors at the input side are coupling capacitors to block any dc offset and the resistor and capacitor networks are for frequency compensation in order to obtain the true amplified audio output.

Stereo audio amplifiers generally refer to using two mono amplifiers and integrating their inputs, having a common ground and supply terminals to get the required stereo provisions. However such circuits generally tend to become too bulky and expensive. We can observe optimum performance of this amplifier when used with dual supply voltages of approximately 16 volts. As previously mentioned, it delivers a good 2 x 12 watts of output power which can be used to drive a pair of 8 ohm or 4 ohm speakers. The amplifier gain is internally calibrated and fixed at 30 dB with a gap of about 0.2 decibels. This ensures a balance of gain between the two output channels.

The output of the IC is protected against overloads and accidental short circuits [13]. The IC also features a thermal runaway protection so that excessive heating will not damage it; however it may shut-off at high temperatures. Therefore it is recommended that the IC is provided a heatsink when the output is subjected to the aforementioned load and supply parameters. The resistor and capacitor network handles frequency compensation and the capacitors on the output side are used to block DC interference/offset in order to get the required true audio output.

B. Actuation

A motor-driven speaker system controlled by a DSP controller is proposed and simulated in [3], in which the DSP controller is used for feedback in order to eliminate the issues of center drift and infrasonic harmonic distortion observed due to the change in coupling mechanism and filtering circuits. Commercially available speakers make use of an elastic belt for coupling which would tear or get incapacitated at the required operating conditions (low frequency and high decibel levels) leading to system failure. In [3], the coupling mechanism has been changed to an aluminum metal-based coupling mechanism which gives rise to the center drift problem due to its rigidity. The DSP controller allows us to control the input voltage and hence the angular displacement of the dc motor used to drive the speaker. A motor driver circuit controlled by the microcontroller will be required to provide the dc motor with appropriate signal level.

Acoustic pressure levels greater than a 100 dB are achievable through this method.

Another alternative is to use a subwoofer having a pair of speaker cones of appropriate size (15” or greater, 21” or 24” is advised) having a high Q-factor.

$$D = \sqrt{(4*d^2+w^2)} \qquad (4)$$

Where:

D = cone diameter

d=depth

w=width

This system can be driven using a high-power, high fidelity amplifier which can supply up to a 1000 watts. The amplifier discussed above is a high fidelity, 12W 2-channel amplifier which is sufficient to drive smaller cones. For 15”-18” cones, a TDA 8953 2x210W amplifier can be used.

Other actuation schemes may include pneumatic actuators which are driven by electronic signals in order to obtain precise control over the output signal amplitude and frequency.

Using the wave generation techniques along with the actuation methods identified above, we can successfully obtain the required low-frequency acoustic waves.

V. APPLICATIONS

The properties of the wave and its effects on the human body as well as on particles give it several possible fields of application. Some of the fields of application being explored today are:

A. Monitoring Natural Phenomena Monitoring earthquakes, charting rock, tsunamis, volcano eruptions and petroleum formations below the earth is made possible by the nature of these waves and their occurrence as a by-product in each of these phenomena. The amplitude and other characteristic information of a recorded infrasonic pulse generated by an eruption can be used to estimate the quantity and acceleration of ejected material as established in [4]. Dominant infrasound signals observed in volcanoes during tremors are usually in the range of 1 to 10 Hz. Thus, infrasonic sensors can be used to monitor eruptions, tremors and other volcanic events, even in clouded or low visibility. The sensors used may be piezoelectric elements or even condenser microphones, which would need certain supplementary electronics including batteries (supply) and some form of data storage or logging or an alarm system using timers and a speaker. In [6], a smart, power-harvesting, self-powered sensor is proposed to be used for monitoring seismic activity and strain on buildings and other structures. Tsunami and storm warning systems can be set up using infrasonic sensors placed at appropriate distances from the coast. It has been observed that fast-travelling infrasonic waves may be generated under water before the occurrence of a tsunami or during severe storms. Using infrasonic and high frequency imaging along with GPS technology, effective sensors having a lower error rate can be developed. Coastal warning systems can be set up; each system consisting of infrasonic sensors as well as systems which detect the electromagnetic phenomena that are associated with these occurrences. These warning systems could help in carrying out timely and effective evacuation. Thus, the monitoring of natural phenomena is a major application for these infrasound waves.

B. Wildlife Conservation and Rail Inspection

One unique application of infrasonic waves and sensors is monitoring the integrity of rails and conserving wildlife like elephants simultaneously. Elephants are protected from being overrun by trains by using infrasound to deter them from crossing the rail track. [9] discusses the use of wireless sensor networks to ensure the conservation of wildlife along the train tracks and crossings. These wireless sensors are similar to the ones used for border protection. The use of infrasound for integrity monitoring is discussed in the following subsection. Since elephants communicate using infrasound, acoustic transducers and sensors can be used to direct their movements. The method described in [9] involves trains spraying passive sensing nodes on either side of the tracks. These would comprise of a pressure based piezoelectric sensor, a button cell to supply required power, a transducer to emit sound and a timer to generate the sound waves as described above. Active sensing nodes would assist the passive ones by driving the elephants away from the railway line. These active nodes collectively would also ensure the safety of the railway track. If an elephant steps on a passive sensing node, the sound emitter will emit a tone for a prefixed time as set by the timer. The sound emitter used would emit the sound in frequency range greater than 12 kHz and less than 20 kHz. On the other hand, active nodes would emit infrasonic sound if a train is approaching.

C. Industrial Applications

Due to their large wavelength, omnidirectional flow and low absorption, infrasonic waves are fast finding applications in the industry today in the form of soot cleaners and for integrity monitoring.

Infrasound acoustical waves can be used to clean soot or ash residue from chimneys and even boilers. Soot collected on the walls and in the tubes of the boiler is dislodged using infrasonic acoustic waves emitted using an appropriately sized loudspeaker or pneumatic actuator. Depending on the size, shape and materials of the boiler or chimney, infrasonic waves of appropriate frequency are generated making use of one of the generation techniques listed above. The generated waves usually lie in the range of 10-30 Hz. The energy of the waves is transmitted to the flue gas and accumulated soot particles get dislodged from the walls.

In pipelines, leakages generate vibrations in the infrasound frequency range which can be detected by sensors. Due to the large wavelength of the signal, it can travel large distances without getting attenuated, allowing sensors to detect small leaks at distances of several kilometers. One of the sensors used for the detection of infrasonic waves is a microbarograph, which is fundamentally a microphone which has been made sensitive to detection of low frequency signals. Infrasonic generators and sensors can be set up on both ends of a pipeline such that the region of leakage can be approximated by the comparison of resultant waves on either side.

D. Study of the Human body

On being exposed to infrasound, some have been found to experience symptoms like fear, nausea, anxiety, chest pressure and hallucinations. The possible use of higher power waves for a multitude of purposes ranging from entertainment to defense or military purposes is being researched currently. However, if used properly, these waves can be used in order to glean knowledge about the body through its effects and by using it for imaging.

Infrasonics may also be used in ballistocardiography and seismocardiography to study the mechanism of the heart. The mechanical behavior of the heart can be likened to that of a pump and this behavior is revealed by the seismocardiogram signals which are in the infrasonic range (less than 20 Hz). The signals can be measured using sensitive transducers which use the displacement, velocity or acceleration of the body when the heart beats. Similarly, the ultra-low frequency range signals can be detected and measured for their use in ballistocardiography for the study of the heart and its mechanical functioning.

VI. CONCLUSION

Hyperventilation caused by whole body vibration, difficulty sleeping, headaches, irritability, concentration and memory problems, nausea, and dizziness; it has been posited that each of these effects are caused as an effect of infrasonic waves having a sufficient decibel level power. This could open up a relatively unexploited area of research for the biological uses of infrasound. The experimental setup explored in this paper can successfully be used to generate infrasonic waves of appropriate amplitude and frequency to contribute to such research.

Aside from its effects on the human body, infrasound has several possible applications; some of which have been discussed in this paper. The nature of infrasonics and the process of its generation find it applications in a variety of ways; right from its use as a precursor or warning signal for imminent danger due to natural disasters, or for protection of wildlife or cleaning of soot from chimneys.

A study of these waves has led us to an implementation of the proposed Infrasonic sound system as that would help us analyze the changes in basic human behavior and psychology, on exposure to frequencies lying within the infrasonic band as well as explore some of the applications discussed in this paper. The system would include a complete circuit for generation of square and sine waves of relevant frequency range as well as the amplifier considered in this paper.

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