Detection of Infrasonic Frequency Loudspeaker Using Microwave Motion Sensor Module

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Abstract. In the last few decades, research on loudspeakers, especially at low frequencies and infrasound, has made significant developments. Among them, the loudspeaker is used as a low-frequency mechanical signal generator to simulate human arterial pulses. An electret condenser microphone (ECM), one of the alternative sensors that will be used to measure the arterial pulse which is simulated by the loudspeaker. Interestingly, neither the mechanical signal generator nor the sensor that will be used has data on infrasonic frequencies or it can be concluded that both of them have not been calibrated.

This paper proposes that the infrasonic signal generated by a moving coil loudspeaker can be observed using a calibrated sensor, a microwave motion sensor. The main contribution of this study is to find the infrasonic loudspeaker frequency response data used in previous studies so that it can be used as a compensator to calibrate ECM as an alternative arterial pulse sensor. Microwave motion sensors have basic concepts such as the Doppler effect principle, which reads an object based on its displacement. Microwave motion sensors can observe the movement of the diaphragm cone of the loudspeaker requires several supporting instruments, including a signal conditioning circuit and an undisturbed environment. In the end, the microwave motion sensor can observe infrasonic acoustic waves and get a compensator value for the ECM as an alternative arterial pulse sensor.

1. Introduction

A loudspeaker is a transducer that converting electrical energy into acoustic energy. Acoustic energy or sound waves generated by loudspeakers have varying frequencies, including infrasound, audio sound, and ultrasonic frequencies. These varying frequencies can be harvested or extracted into other forms of energy or to analyze a study [1]. In recent years, there has been an increasing amount of literature on loudspeakers as sound wave frequency generators [2]. This idea was supported in previous work [3], [4] [5] [6], which revealed that electromechanical actuators help medical diagnostics a lot in modeling biomedical signals in the human body. One example is a loudspeaker which can be used as a generator of sound waves at infrasonic frequencies [7] [8]. Heartbeat modeling uses a loudspeaker as an infrasonic frequency generator which is useful for analyzing a data acquisition and also for calibrating an alternative sensor such as electret condenser microphone (ECM). Interestingly, the loudspeaker as an acoustic frequency generator is still unknown how the infrasonic frequency response even though the datasheet is not stated. Meanwhile, to calibrate an alternative sensor, the tool used (in this study, the loudspeaker) must be calibrated or the infrasound frequency response is known. However, there is still little published data on how to observe infrasound frequencies, especially on moving coil loudspeakers. In addition, no paper has comprehensively reviewed the measurement of infrasonic frequencies in loudspeakers under test. Because there are no experiments
that validate this case, this work will pave the way for discovering the infrasonic frequency response on a loudspeaker. Movable coil loudspeakers on common datasheets typically have an audio frequency response (20-20,000 Hz). However, observational experiments in infrasonic frequencies make it possible to study [9]. Observation of infrasonic frequencies in the 2-20 Hz range is necessary to remove interference from the environment (such as walls, mesh frequencies, people walking, etc.), conditioned design systems with minimum disturbances. The sensor used has several criteria, including the sensor has been calibrated, then the sensor used does not affect the movement of the loudspeaker cone, meaning that it does not contact directly so that there is no load affecting it. Based on this, observing the frequency response of the infrasonic loudspeaker in this study used a microwave motion sensor.

**Figure 1. General design system**

In general, the system is designed to use several main components, including a loudspeaker, a microwave motion sensor (in this work using HB100 module), and a room with minimal interference to get maximum results. Simply, the system can be demonstrated in Figure 1. Starting from the power amplifier that drives the loudspeaker under test, then the loudspeaker will produce acoustic waves which will be observed by the microwave motion sensor (HB100) to be analyzed comprehensively. The loudspeaker and HB100 sensor are placed in a mini anechoic chamber to focus the signal from the microwave motion sensor separated by 1 cm of air medium to avoid sound propagation through solid objects. This system is designed and built in the laboratory of the control system of Brawijaya University. The loudspeaker tested used the SC 5.9 8 ohm full range type and the microwave motion sensor used HB100 sensor (shown in Figure 2).

**Figure 2.** (a). Microwave motion sensor, (b). Movable coil full-range loudspeaker

2. **Methodology**

Frequency response describes the output spectrum usually magnitude and phase of the system or device. The magnitude and phase of the loudspeaker value indicate the characteristics of its acoustic movement which are determined by the loudspeaker cone diaphragm [10][11]. So we know the magnitude and phase by observing the movement of the loudspeaker cone. The frequency response is used to describe the range of frequencies a loudspeaker can produce. In general, the frequency produced by a loudspeaker corresponds to human hearing, from about 20 Hz to 20 kHz. However, it is not impossible that loudspeakers are able to reproduce all or more of the audible frequency range. The detailed structure of the movable coil speaker is shown in Figure 3. At the front of the loudspeaker is a thin layer of paper or a light metal cone (called a diaphragm) which is then attached to a metal loop on the outside. On the inside, an iron coil is installed right in front of the permanent magnet. When the loudspeaker is energized through the cable into the coil, the coil becomes a temporary magnet or
When the electric current flows continuously through the cable, an electromagnetic field occurs which causes the coil to move back and forth, pulling and pushing the loudspeaker cone. The movement of the loudspeaker cone will produce sound waves.

**Figure 3.** Structure movable coil loudspeaker

Based on the explanation at the beginning, this research uses sensors that have been calibrated and are not in direct contact so as not to overload the movement of the loudspeaker cone. Based on these requirements this study uses the HB100 sensor as a microwave sensor. In another study, this sensor could detect very low frequencies with an accuracy of 98% [13]. The HB100 module has a basic working base on the Doppler effect rules [14]. The sensor will emit a certain frequency on an object to be observed, then the object will reflect that frequency which will be received by the sensor receiver, and finally, the sensor will compare the emitted and received frequencies to describe the object's position [15]. The movement of the diaphragm cone on the loudspeaker is like a periodic pendulum motion shown in Figure 4. The movement that occurs in this loudspeaker will represent a sinusoid signal. However, it has a phase difference of 90 degrees which is different from the original input signal. This is because the maximum speed of the loudspeaker cone occurs in the neutral position and the minimum speed of the loudspeaker cone in the convex or concave position of the loudspeaker. However, even though the wave phase is different, it can describe the frequency response. Movement of the convex-concave of the loudspeaker cone, just like a sinusoidal wave as in Figure 4.

**Figure 4.** The movement of the loudspeaker cone and the sinusoidal wave sensor

The specification of the loudspeaker under test shown in Table 1. [16]

| Parameter | Value   | Unit  |
|-----------|---------|-------|
| $R_e$     | 6.28    | Ω     |
| $L_e$     | 0.403x10^{-3} | H     |
| $B_l$     | 3.14    | T.m   |
| $L_m$     | 4x10^{-3} | Kg    |
| $R_m$     | 50      | Ns/m  |
| $C_m$     | 2x10^{-3} | N/m  |

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electromagnet [12].
The system conditioning design to minimize disturbance from the surrounding environment can be shown in Figure 5. In this study, both the loudspeaker and motion sensor were placed in a mini anechoic chamber with a size of 445 x 355 x 250 mm to obtain a valid value. And the two are separated by an air medium to avoid vibrations from the loudspeaker spreading through the solid.

![Figure 5. Mini anechoic chamber design](image)

The system is also coated with a vibration damper and is shaped like a triangular pyramid to prevent the signal pattern emitted by the sensor from spreading and being focused on the object being observed. In addition, the system is also coated with a 1 cm thick sponge to help reduce vibrations that occur both from outside and from within the system. The schematic design system is shown in Figure 6. Starting from the frequency generator (FG) and class A amplifier so that frequency switching is not overwhelmed. The input signal from the frequency generator will be amplified by a class A power amplifier which aims to make the output signal the same as the input signal. Figure 6 schematic system flowchart, first the input signal from the function generator is amplified by the class A amplifier in order not to change the original signal, then the class A amplifier output will activate the loudspeaker. Acoustic waves from the loudspeaker will be transmitted and read by HB100. HB100 output signal will be amplified by an analog amplifier and will be forwarded to the oscilloscope. In the oscilloscope, the HB100 output signal is compared with the original signal before and after amplification.

![Figure 6. Schematic system](image)

From the system scheme, there are three signals to be compared. The input signal from the frequency generator, then the class A amplifier output signal, and finally the motion sensor output signal (HB100). Two signals will be analyzed in depth. The output signal from the class A amplifier and the output signal from the HB100. One way is to compare the magnitude of $|H(j\omega)|$ and phases $\angle H(j\omega)$ to each other.

3. Result and Discussion
Observing the signal made to the system, getting three signals as in Figure 7 (a) The yellow line sinusoid signal is the signal from the frequency generator, then the blue line sinusoid signal is the
amplifier output signal, then the red line sinusoid signal is the HB100 sensor output signal and Figure 7 (b) is the FFT impulse of the HB100 output signal.

Figure 7. All signal in the system (a), and FFT impulse system from HB100 (b)

Recording the signal in the system using an oscilloscope, it is concluded that the HB100 sensor can read the movement of the loudspeaker cone according to the frequency of the input signal but has a different amplitude and phase. The relationship between the signal input of the class A signal amplifier and the HB100 sensor signal output is like the principle of the Doppler effect. The phase difference between the two input signals from the amplifier and the sensor output is approximately 90 degrees. This is because the sensor reads based on its displacement. This means that when the cone diaphragm speed is zero, the position of the loudspeaker cone is in a concave or convex position (in this position the input signal amplitude is at its peak) then the sensor reads the condition with a zero value (in this position the output signal amplitude is zero), vice versa when the diaphragm speed maximum cone (at this position the loudspeaker condition is neutral and the input signal amplitude is zero) then the sensor reads it with the peak value. This condition will be repeated periodically and will describe a signal. This signal will be extracted again using Fourier Transform (FFT) to get the peak magnitude of the captured frequency. We used MATLAB as the FFT analyzer and the frequency extraction was carried out at a frequency of 2 Hz to 20 Hz in dBm units. After that, the peak value obtained will be drawn on a graph. This illustrates the amplitude value at each frequency, this value also represents the frequency response.

Figure 8. The infrasonic frequency response of loudspeaker under test

The observation results on the system can be seen in Figure 8, the loudspeaker characteristics obtained based on the frequency domain analysis. The moving speed of the loudspeaker cone gets smaller as
the frequency decreases, this makes the amplitude captured by HB100 from the loudspeaker also smaller. To validate this experiment, here with some results on other work [17][18], high power electroacoustic speaker performance at infrasonic frequencies has almost the same trends and patterns. The response is shown in Figure 9. the smaller the frequency, the smaller the amplitude with the frequency. The shape is slightly different because the parameters of the loudspeaker generator are different but the two types of loudspeakers are the same, namely the moving coil loudspeaker, so the basic characteristics are the same.

![Figure 9. Comparison between high power electroacoustic speaker and loudspeaker under test](image)

4. Conclusion
In this study, the observation of acoustic waves at infrasonic frequencies generated by coil loudspeakers using microwave sensors has been proposed. Observation without overloading the loudspeaker cone is one thing that must be considered to see the frequency response. Observations using the HB100 sensor show the response to the movement of the loudspeaker cone which describes the frequency response. The movement of the cone will weaken as the frequency decreases, so the amplitude will be smaller too. This experiment can be validated with the response of high power electroacoustic speakers, although the parameters are different the resulting characteristics are the same if the amplitude of the output signal will be smaller in proportion to the smaller the input signal frequency. This characteristic in the future can be used as a compensator to calibrate the electret condenser microphone (ECM) as an alternative arterial pulse sensor.

5. References
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