

The conversion of acoustic and mechanical vibrations into their equivalent electrical signals using simple circuit instruments

Bahram Jazi (1)*

¹Department of Photonics-Plasma , Faculty of Physics, University of Kashan, Kashan, I.R. of Iran

Abstract

In this study, we demonstrate that mechanical and acoustic oscillatory energy can be converted into electrical signals using a simple circuit that is easy for college and introductory undergraduate students to understand. We also provide a theoretical explanation showing that the proposed configuration is suitable for this energy conversion. The experimental setup requires only a DC voltage source, an ohmic microphone, a tuning fork, a high-value resistor, and an oscilloscope, making it accessible and easy to implement in typical teaching laboratories.

Introduction

*One of the major achievements in electronic sciences is the conversion of variations in different physical phenomena into their corresponding electrical variations [1]. In this regard, one significant accomplishment has been the conversion of mechanical and acoustic vibrations into their **corresponding** electrical signals [2]. If mechanical and acoustic oscillations are properly converted into their equivalent electrical oscillations, this provides us with a useful tool to teach students and researchers. For example, when we have the sound vibrations of a tuning fork, we can observe the equivalent voltage variations of those vibrations on an oscilloscope. In the continuation of this paper, we introduce a simple device, one that does not rely on complex electronic circuits, that performs the conversion of acoustic energy into an electrical signal [3]. This allows the generated signal to be easily observed on a basic oscilloscope, both theoretically and experimentally.*

The theoretical foundations and background of the proposed mechanism

As shown in Figure 1, consider a DC power supply that, with good stability, can provide the desired DC voltage under various conditions (high stability combined with very low internal resistance)[3].

A relatively stable DC power supply
with an output voltage V_0

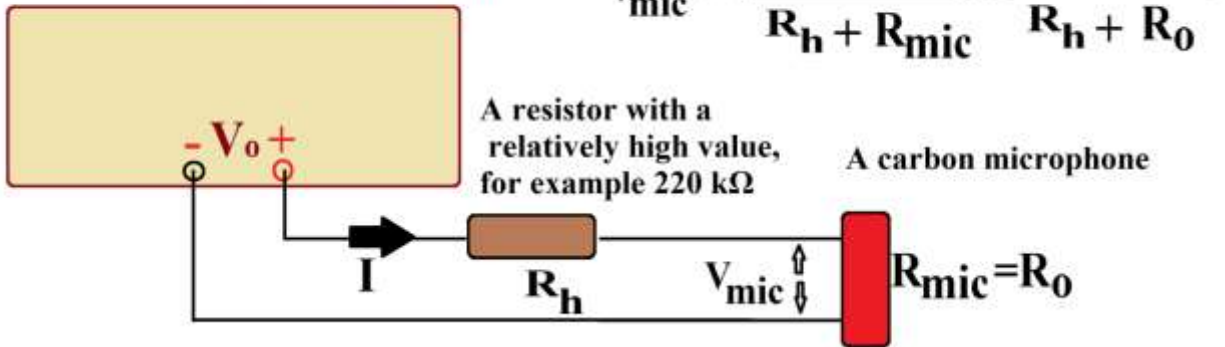


Figure 1: The arrangement of a relatively stable DC power supply connected to a **carbon** microphone through a comparatively large resistor. The figure illustrates the situation in which no acoustic wave is present in front of the microphone, and the voltage across the microphone terminals remains constant.

Here, we assume the device's output voltage is set to the relatively large value V_0 , and that this output is connected through a relatively large resistor (for example, $R_h \geq 200K\Omega$) to a **Carbon** microphone (a type of **ohmic** microphones). It should be noted here that, since before placing the microphone in front of a sound wave, there is no time-periodic signal at all, and the entire signal applied to the system is only a DC voltage, the use of capacitive, inductive, or even crystal microphones has been avoided. There are two main reasons for this choice. First, the capacitive and inductive effects in microphones typically manifest themselves in the presence of alternating signals (carrier signals). Second, students are more familiar with the mathematical analysis governing circuits that include real ohmic resistors than with the mathematical analysis of complex numbers used for interpreting AC signal circuits. Here, the ohmic resistance of the microphone in the absence of any acoustic vibration near it is considered to have a relatively high value, such as R_0 . In the situation shown in Figure 1, there is no sound wave in front of the microphone; therefore, the voltage across the microphone is simply obtained as a DC signal from the relation provided in Figure 1. As shown in Figure 2, R_0 varies in proportion to the vibrations of its sensitive diaphragm when sound is applied, expressed as

$$R_{mic}(t) = R_0 + R_s(t)$$

where in the above equation, $R_s(t)$ represents the portion of the small variations in the microphone's resistance when it is exposed to sound or acoustic vibrations, and its magnitude is on the order of milliohms or ohms. The value of $R_s(t)$ can generally be small and may have either positive or negative signs, originating from the vibrations of the sensitive diaphragm in the microphone, which moves backward or forward. However, it should be noted that, given the large value of R_0 and the very small magnitude of $R_s(t)$, the microphone's instantaneous resistance $R_{mic}(t)$ never becomes negative.

As also shown in Figure 2, since a sound wave is present in front of the microphone, the voltage across the microphone $V_{mic}(t)$, varies with time due to the variation of the microphone's resistance $R_{mic}(t)$. This voltage is shown in Figure 2 in the first-order approximation. As is evident from the relation provided in Figure 2, the voltage across the microphone consists of a DC voltage and a time-varying component.

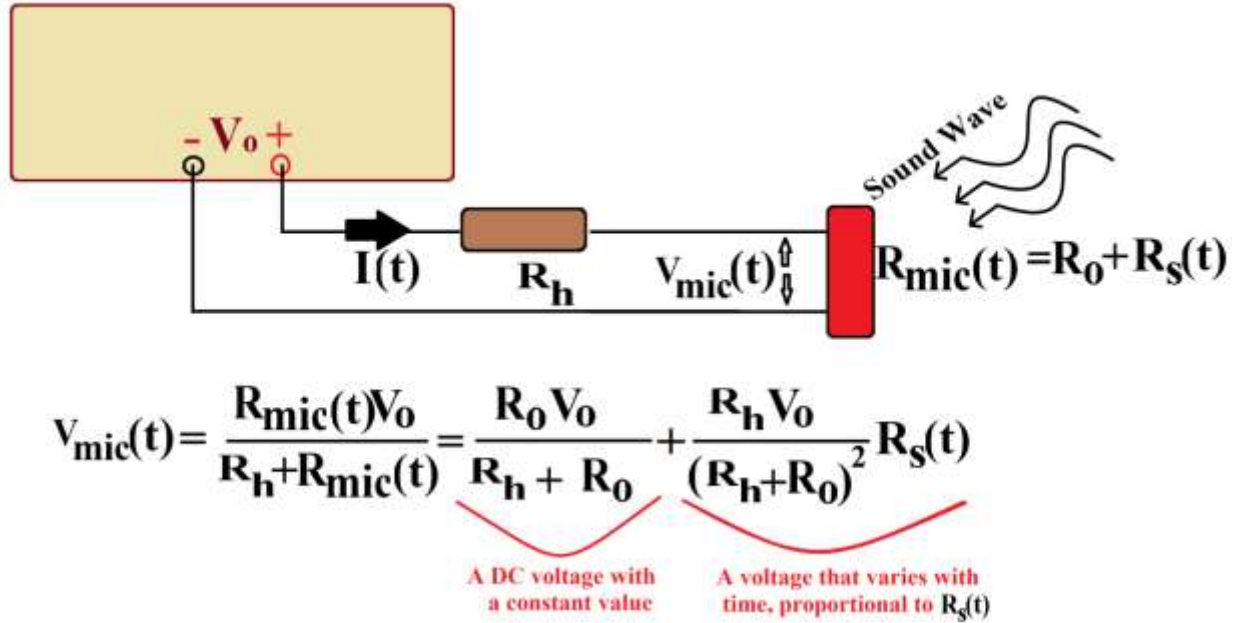


Figure 2: The variation of the microphone's resistance and consequently the voltage across its terminals when it receives an acoustic wave.

To further help students understand, we briefly outline the process and method of calculating the voltage across the microphone in the following. We start with the familiar basic relation for the voltage across the microphone, namely the following relation

$$V_{mic}(t) = \frac{V_0 R_{mic}(t)}{R_{mic}(t) + R_h}$$

Then, by factoring out the relatively larger terms and moving the denominator of the fraction to the numerator and expressing it with a negative power, we will have

$$V_{mic}(t) = \frac{V_0 [R_0 + R_s(t)]}{R_h + R_0 + R_s(t)} = \frac{V_0 R_0}{R_h + R_0 + R_s(t)} + \frac{V_0 R_s(t)}{R_h + R_0 + R_s(t)}$$

$$V_{mic}(t) = \frac{V_0 R_0}{R_h + R_0} \left[1 + \frac{R_s(t)}{R_h + R_0}\right]^{-1} + \frac{V_0 R_s(t)}{R_h + R_0} \left[1 + \frac{R_s(t)}{R_h + R_0}\right]^{-1}$$

Using Newton's binomial expansion and neglecting the terms in which powers of $R_s(t)$ of second order or higher appear, we will have

$$V_{mic}(t) = \frac{V_0 R_0}{R_h + R_0} + \frac{V_0 R_h}{[R_h + R_0]^2} R_s(t)$$

For example, if the sound oscillations vary harmonically at a single frequency F_f with angular frequency $\omega_w = 2\pi F_f$ in front of the microphone, its instantaneous resistance will be $R_{mic}(t) = R_0 + a \cos(\omega_f t)$ where a is a very small value in **Ohms** as shown in Figure 3.

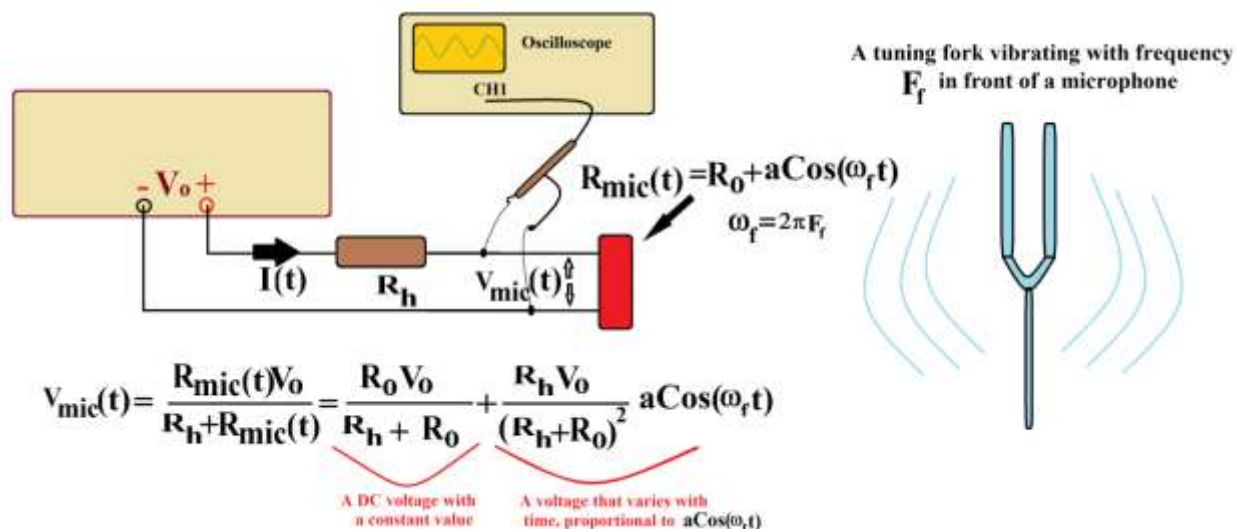


Figure3: Placing a vibrating tuning fork in front of the microphone, making the voltage across the microphone periodic, and observing single-frequency quasi-sinusoidal oscillations on the oscilloscope.

As can also be seen in Figure 3, one of the methods to generate an approximately harmonic (sinusoidal) single-frequency sound wave is to use a tuning fork with a specific frequency, and this is illustrated in Figure 3. In Figure 4, you see an experimental setup corresponding to what is shown in Figure 3. In Figure 4, a tuning fork is vibrating in front of the microphone at an operating frequency of 370 Hz, which can be observed on the oscilloscope.

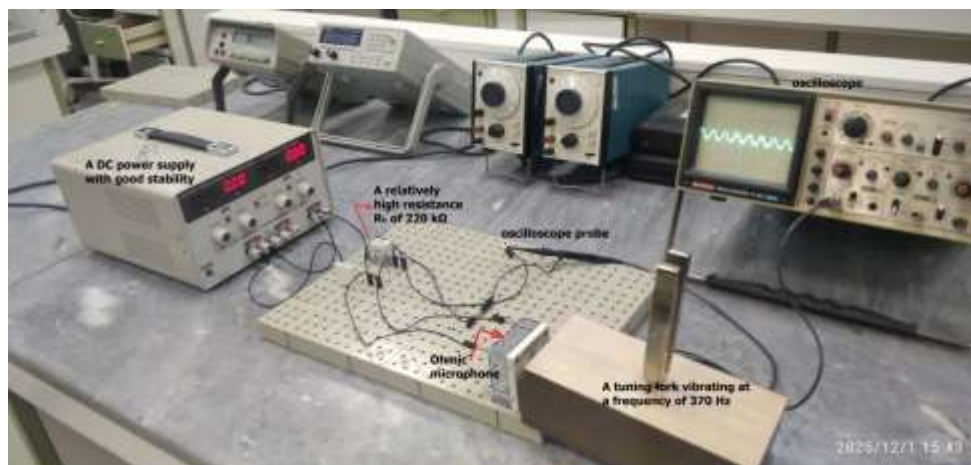


Figure 4: Illustration of an experimental setup corresponding to the configuration shown in Figure 3.

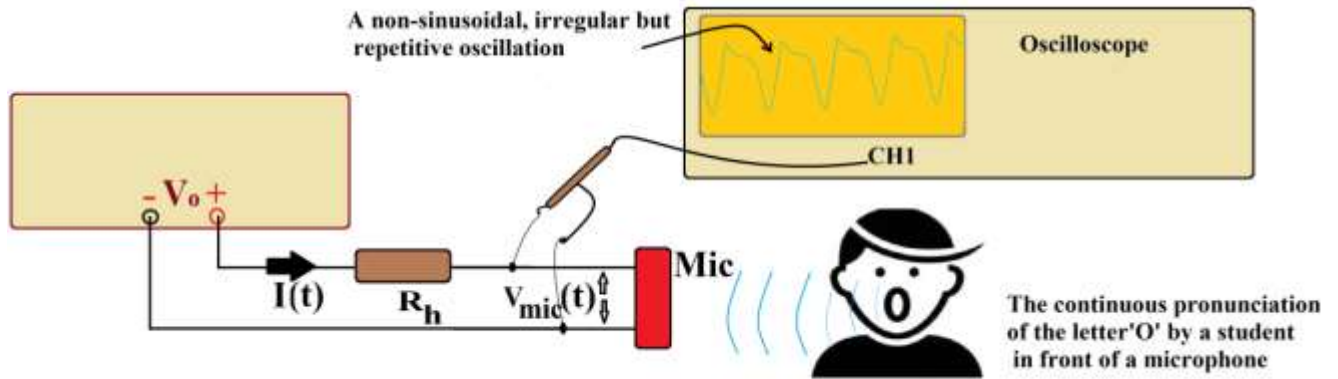
To help students better understand the concepts of sound wave generation by musical instruments and even by the human larynx, this setup can provide a better perspective on the shape of the oscillations in question. For this purpose, in the following section of this article, we propose a student activity in which students are asked to complete the tables provided below after setting up the circuit, in order to become familiar with the concepts of sound waves.

Student activity using the presented setup for a deep understanding of the concepts of sound oscillations

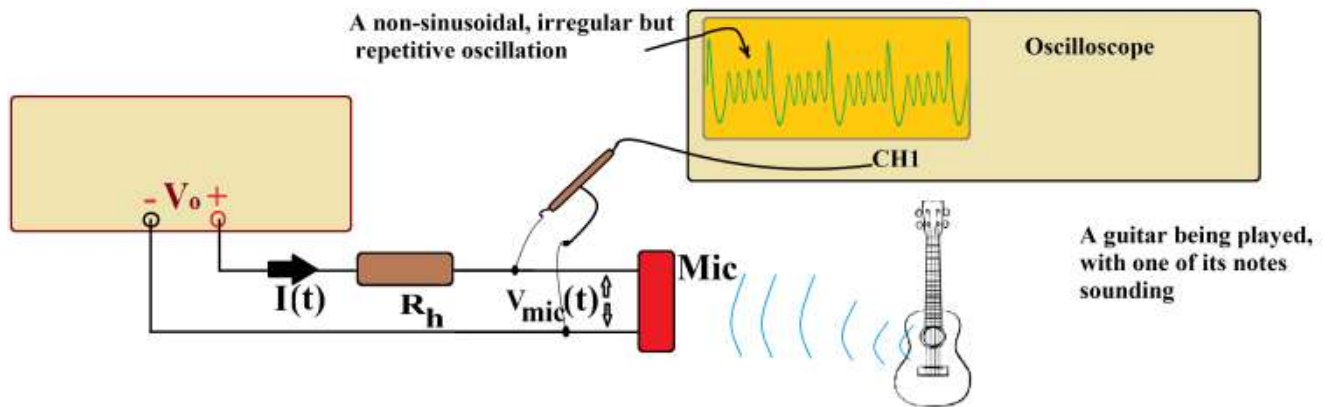
Aims of carrying out this activity by the students:

In this activity, which is listed below, students should learn that the waveform profile of sound signals produced by the human larynx or by musical instruments is not necessarily a single-frequency sinusoidal or cosinusoidal signal. The student will learn that under specific conditions (for example, when the sound signal is generated using a tuning fork), the signal profile becomes single-frequency sinusoidal. The student will also learn what similarities and differences the continuous pronunciation of letters has for different individuals. Additionally, the student will learn this for sounds produced by musical notes. The activities are as follows:

- A) The student should be asked to prepare an experimental setup according to Figure 2.*
- B) To observe approximately harmonic single-frequency oscillations, perform the experiment shown in Figure 3 using three different tuning forks whose oscillation frequencies are specified by the manufacturer, and take a picture of the oscilloscope trace with their mobile phone.*
- C) Using the oscilloscope's time/division setting, determine the period, and then by taking its reciprocal, obtain the frequency of the signal observed on the oscilloscope for each tuning fork, and compare it with the manufacturer's value.*
- D) As shown in Figure 5-a, one of the female group members and one of the male group members who are able to pronounce the words 'O' and 'Ah' continuously should say these words in front of the microphone, and the rest of the students should take pictures of the signal displayed on the oscilloscope using their mobile phones.*
- E) At this stage, the student should observe that the continuous pronunciation of words produces a non-sinusoidal but periodic sound signal, and should be able to conclude that the general shape of continuous word pronunciation is roughly the same for girls and boys, with only minor differences.*
- F) Using the time/division setting on the oscilloscope, determine the fundamental frequency of each of the letter pronunciations mentioned in the previous sections and compare them with each other.*
- G) Students are asked to excite a guitar in front of the microphone according to the setup shown in Figure 5-b for two or three different notes. After taking pictures of the signal waveform displayed on the oscilloscope screen and measuring the fundamental frequency of the signals, the students should understand that each note of a guitar or any musical instrument is not completely harmonic and single-frequency, but is periodic.*
- H) Finally, the students should be able to complete the following table and provide a full explanation and interpretation of what they have observed in their lab report.*



5-a



5-b

Figure5: The setup for examining the shape of sound signals resulting from the pronunciation of letters by the larynx (Figure 5-a) and examining the shape of sound signals for different notes of a guitar (Figure 5-b).

The experiment for investigating sound signals of a tuning fork, according to Figure 3.		
The operating frequency of the first tuning fork=-----	The operating frequency of the second tuning fork=-----	The operating frequency of the third tuning fork=-----
The measured frequency for the first tuning fork=-----	The measured frequency for the second tuning fork=-----	The measured frequency for the third tuning fork=-----
The image of the tuning forks' signal on the oscilloscope		
?	?	?
The experiment for investigating sound signals of continuous pronunciation of letters, according to Figure 5-a.		
Conducting the experiment by a female student		
The measured frequency for the continuous pronunciation of the letter 'Ah'=-----	The measured frequency for the continuous pronunciation of the letter 'O'=-----	
The observed image on the oscilloscope for the continuous pronunciation of the letter 'Ah'	The image observed on the oscilloscope for the continuous pronunciation of the letter 'O'	
?	?	
The experiment for investigating sound signals of continuous pronunciation of letters, according to Figure 5-a.		
Conducting the experiment by a male student		
The measured frequency for the continuous pronunciation of the letter 'Ah'=-----	The measured frequency for the continuous pronunciation of the letter 'O'=-----	
The observed image on the oscilloscope for the continuous pronunciation of the letter 'Ah'	The image observed on the oscilloscope for the continuous pronunciation of the letter 'O'	
?	?	
The experiment for investigating sound signals of a guitar for three different notes, according to Figure 5-b.		
The measured signal frequency for the first note=-----	The measured signal frequency for the second note=-----	The measured signal frequency for the third note=-----
The image of the signals of the three notes on the oscilloscope		
?	?	?

Tble 1: Table 1 for recording the data obtained during the student activity process

Conclusion, summary, and development of the setup:

In this article, avoiding the complexities involved in modulation systems, we have attempted to present a simple circuit, within the understanding level of senior college students, to make it possible to observe the conversion of sound signals into their equivalent electrical signals. It will be interesting for students to understand that continuous sound signals are not necessarily single-frequency harmonic signals, but they do have a repetitive profile, and this was demonstrated by the setup presented in this article. This setup can be upgraded by replacing the DC power supply with a high-frequency signal source, and it can also demonstrate the concepts of amplitude modulation of sound signals onto a high-frequency carrier signal.

References

- ١) Paul Horowitz , Winfield Hill, The Art of Electronics, 3rd Edition, Cambridge University Press Pub., ISBN:0521809266,(2015)

- ۲) *George Dekoulis, Modulation in Electronics and Telecommunications, Intechopen Pub., ISBN:178985489X, (2020).*
- ۳) *Nihal Kularatna ,DC Power Supplies: Power Management and Surge Protection for Power Electronic Systems,CRC Press Pub., ISBN:978-0415802482, (2018).*