

## ENERGY DEGRADATION OF SOUND WAVES OF DIFFERENT FREQUENCIES

### DEGRADAÇÃO ENERGÉTICA DE ONDAS SONORAS DE DIFERENTES FREQUÊNCIAS

### DEGRADACIÓN ENERGÉTICA DE LAS ONDAS SONORAS DE DIFERENTES FRECUENCIAS



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Júlia Delducca Neto dos Santos Ribeiro<sup>1</sup>, Raíssa Freitas dos Santos<sup>2</sup>, Laura Machado da Silva Borges<sup>3</sup>, Roberto Soares da Cruz Hastenreiter<sup>4</sup>, José Sampaio de Oliveira<sup>5</sup>

#### ABSTRACT

The specific mechanisms present in sound wave propagation models are of interest to many fields. In this sense, determining the energy degradation of sound is fundamental to the production of knowledge. In this work, we will analyze the attenuation of sound intensity as a function of distance considering different frequencies. We used a 100 Watt RMS source in a wide corridor of the IFRJ, Rio de Janeiro Campus, at a time when no activity was being carried out. Thus, we evaluated the sound intensity emitted from the source every 50.0 centimeters using a decibel meter. Intensity measurements were taken from the vicinity of the source to a distance of 15.0 meters, totaling 30 measurements. We used three different frequencies for each of the 30 measurements. The first was 400 Hertz, the second a frequency of 1600 Hertz, and the last at the beginning of the spectrum considered high-pitched for humans, at 3200 Hertz. These results were graphically projected to compare whether the attenuation of sound intensity with distance is frequency-dependent. We performed two adjustments with different functions for each set of measurements of the three frequencies in order to compare whether attenuation can be observed in the two models. From these adjusted functions, we compared the attenuation of sound intensity using their derivatives.

**Keywords:** Attenuation. Frequency. Intensity.

<sup>1</sup> Biotechnology Technician. Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ). E-mail: juliadelducca13@gmail.com Lattes: <https://lattes.cnpq.br/4462125230912986>

<sup>2</sup> Biotechnology Technician. Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ). E-mail: raissa.freitas.santos@gmail.com Lattes: <https://lattes.cnpq.br/9070771383986510>

<sup>3</sup> Chemistry Technician. Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ). E-mail: lauramachado.sborges@gmail.com Lattes: <https://lattes.cnpq.br/5165443078394472>

<sup>4</sup> Interunit Dr. in Science Education. Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ). E-mail: roberto.cruz@ifrj.edu.br Lattes: <https://lattes.cnpq.br/7714359088611369>

<sup>5</sup> Dr. in Geophysics. Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro (IFRJ). E-mail: jose.oliveira@ifrj.edu.br Lattes: <https://lattes.cnpq.br/8629808348018108>

## RESUMO

Os mecanismos específicos presentes nos modelos de propagação de ondas sonoras são de interesse de muitas áreas. Nesse sentido, a determinação da degradação de energia do som é fundamental para a produção de conhecimento. Neste trabalho faremos a análise da atenuação da intensidade sonora em função da distância considerando diferentes frequências. Utilizamos uma fonte de 100 Watts RMS em um amplo corredor do IFRJ, Campus Rio de Janeiro, em um momento em que não havia nenhuma atividade sendo desenvolvida. Assim, avaliamos a intensidade sonora, emitida a partir da fonte, a cada 50,0 centímetros, com um decibelímetro. As medidas de intensidade foram realizadas desde a adjacência da fonte até uma distância de 15,0 metros, totalizado 30 medidas. Utilizamos três frequências diferentes para cada uma das 30 medidas. A primeira com 400 Hertz, a segunda, uma frequência de 1600 Hertz, e, a última no início do espectro considerado agudo para seres humanos, de 3200 Hertz. Esses resultados foram projetados graficamente de maneira a se comparar se a atenuação da intensidade sonora com o distanciamento é dependente da frequência. Realizamos dois ajustes com diferentes funções para cada conjunto de medidas das três frequências a fim comparar se a atenuação pode ser observada nos dois modelos. A partir dessas funções ajustadas, realizamos a comparação na atenuação da intensidade sonora por meio de suas derivadas.

**Palavras-chave:** Atenuação. Frequência. Intensidade.

## RESUMEN

Los mecanismos específicos presentes en los modelos de propagación de ondas sonoras son de interés para muchos campos. En este sentido, determinar la degradación energética del sonido es fundamental para la producción de conocimiento. En este trabajo, analizaremos la atenuación de la intensidad sonora en función de la distancia, considerando diferentes frecuencias. Utilizamos una fuente de 100 vatios RMS en un amplio pasillo del IFRJ, Campus de Río de Janeiro, en un momento en que no se realizaba ninguna actividad. Así, evaluamos la intensidad sonora emitida por la fuente cada 50,0 centímetros utilizando un sonómetro. Las mediciones de intensidad se tomaron desde las proximidades de la fuente hasta una distancia de 15,0 metros, totalizando 30 mediciones. Utilizamos tres frecuencias diferentes para cada una de las 30 mediciones. La primera fue de 400 Hertz, la segunda de 1600 Hertz y la última al inicio del espectro considerado agudo para los humanos, a 3200 Hertz. Estos resultados se proyectaron gráficamente para comparar si la atenuación de la intensidad sonora con la distancia depende de la frecuencia. Realizamos dos ajustes con funciones diferentes para cada conjunto de mediciones de las tres frecuencias con el fin de comparar si se observa atenuación en ambos modelos. A partir de estas funciones ajustadas, comparamos la atenuación de la intensidad sonora utilizando sus derivadas.

**Palabras clave:** Atenuación. Frecuencia. Intensidad.

## 1 INTRODUCTION

Acoustics, as a fundamental branch of physics, is dedicated to the study of phenomena related to the generation, propagation and reception of sound waves. Sound is understood as a mechanical disturbance within a material medium, being generated when a source performs regular vibrations, capable of causing compressions and rarefactions in the environment around it. It is these pressure alternations, propagated in the form of longitudinal waves, that characterize the sound phenomenon. Because it does not propagate in a vacuum, the existence of sound is conditioned by the presence and properties of a material medium that directly influence its characteristics. Acoustics ranges from the physical principles of the wave to the complex social, environmental and technological implications of sound, making it interdisciplinary par excellence.

Acoustic comfort in built environments, for example, depends on the mastery of these parameters to plan insulation, absorption, reverberation time, diffusion and control of unwanted noise. Without this knowledge, auditing, classrooms, hospitals, offices, and even homes could present severe intelligibility problems, sound malaise, and negative impacts on quality of life (Brandão, 2011). The modeling and design of acoustic environments has become a specialized field, responsible for the integration of normative recommendations, subjective criteria, and rigorous quantitative methods. The classical and contemporary literature on acoustics presents an integration between theoretical content and practical applications. Kinsler *et al.* (2000) established a milestone in the systematization of the principles of sound waves, providing the mathematical and experimental bases for the study of propagation media, sound reflections, interferences, resonance phenomena and noise control techniques. Bistafa (2018) and Santos *et al.* (2020), compile engineering and noise analysis solutions in industrial and urban environments, describing in detail measurement practices, normative aspects, noise sources, acoustic barriers, and control practices. The concern with noise pollution and its harmful effects occupies a growing space in the scientific debate, especially in large cities, where demographic growth and the intensification of road, industrial and air traffic exponentially increase the population's exposure to continuous noise. Bressane *et al.* (2010) highlights that noise pollution directly affects hearing and mental health, interferes with cognitive functions and sleep, and can cause persistent disorders. To mitigate these effects, public policies and technical standards have been improved and depend on a deep understanding of acoustic principles and the performance of qualified specialists. In the context of sound perception and acoustic comfort, Hirashima and Assis (2017) report how the configuration of spaces, materials used and architectural characteristics alter the auditory experience of users, reinforcing the need for a

multiprofessional approach and precise instrumental resources for the diagnosis and proposal of improvements in built environments, especially in open urban spaces.

From the investigative perspective of students at the technical level, the teaching of basic acoustics is equally strategic, both for the training of professionals in the exact sciences and for the development of practical and cognitive skills. According to Ferreira *et al.* (2019), didactic sequences that articulate experimentation, computer simulation, and analysis of real situations contribute to the development of critical thinking, the contextualization of scientific content, and the understanding of the social role of science. Soares (2018) also argues that the use of musical instruments as a pedagogical resource streamlines the teaching of acoustic concepts, facilitating the understanding of vibrational phenomena and the relationship of these principles with everyday life. However, few studies deal with specific properties of sound propagation, and the treatment that can be given in an investigative process with technical high school students.

In this work we propose a study of the energetic degradation of sound for different frequencies. The study, based on experimentation, proposes the emission of a sinusoidal sound signal in a large environment and the measurement of the sound level recorded with a decibel meter. In other words, we propose the construction of a function of the sound intensity recorded with the distance for sounds of different frequencies. Since the decays of the adjusted functions are not the same, we can, through this study, determine which type of sound, bass or treble, degrades more energy when propagating in an environment designed with school architecture.

## 2 OBJECTIVE

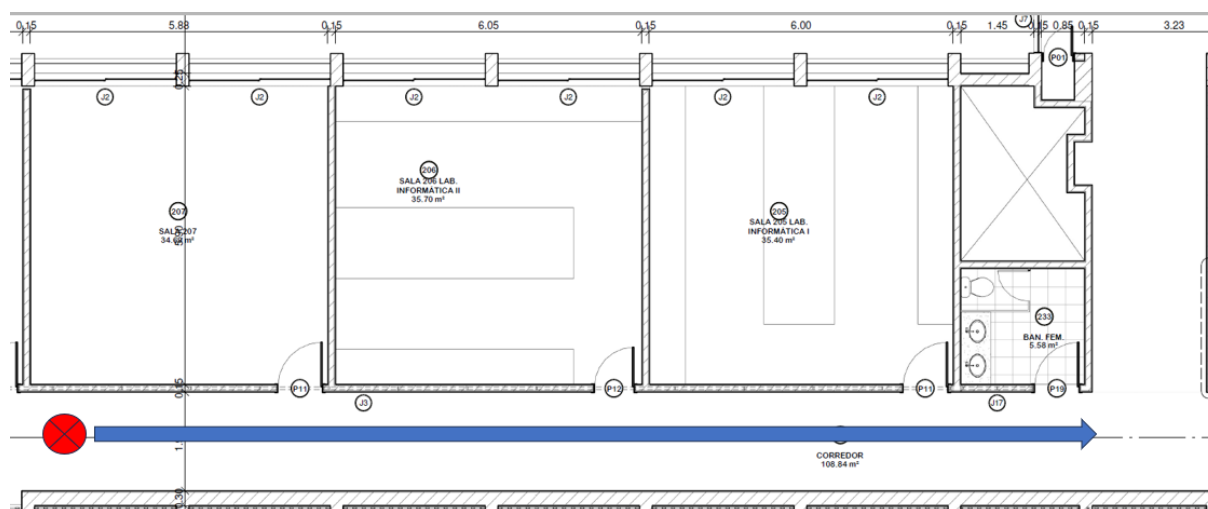
In this work we aim to quantitatively investigate, from more than one mathematical model, which types of sounds, low or high, have a greater energy degradation during their propagation. In other words, we aim to determine who suffers the greatest attenuation.

## 3 MATERIALS AND METHODS

The acquisition of sound intensity data to determine the sound attenuation of sounds of different frequencies was carried out in a corridor of the Federal Institute of Education, Science and Technology of Rio de Janeiro – IFRJ – Rio de Janeiro Campus. A part of the floor plan of the building where the corridor where the measurements were acquired is located can be seen in **Figure 1**. The spatial markings in the architectural plan show the limits of the classroom doors and the meeting between the corridor that connects the two buildings of the Campus.

**Figure 1**

Architectural plan of the corridor, represented by the blue arrow, where the sound intensity measurements were performed. The red target indicates the position of the sound source used to produce the sinusoidal signal



Source: Authors.

We used as a sound source a portable speaker with a maximum intensity of 100 Watts RMS that was placed centered in the corridor as shown in **Figure 1**. The source with power in RMS – *Root Mean Square* – ensures that there are no peaks in emitted sound intensity. Also as a way to ensure the maximum intensity of the source throughout the measurement process, the source was plugged into the socket so as not to cause a reduction in intensity due to a decrease in battery charge. For this investigative process, we applied three sinusoidal signals of different frequencies to the source. We used the frequencies of 400 Hertz, considered as low sound, and the frequency of 3200 Hertz as high. To ensure that the results found are not coincidental, and to reinforce the conclusions, we also used a 1600 Hertz signal for the boundary between low and high sound. Once the sound source is established, we used a 50-meter millimeter tape measure to measure the sound intensity of the source every 50.0 cm. We performed measurements in the corridor shown in **Figure 1** up to a distance of 15 meters, totaling 30 measurements for each of the frequencies investigated. We use a decibel meter with a measuring range of 30 dB to 130 dB and an accuracy of  $\pm 1.4$  dB. We opted for the slow sampling option that captures ambient noises and presents the measurements every 1 s to avoid measuring transitional data beyond the sound intensity emitted by the source itself. The materials used can be seen in **Figure 2**.

## Figure 2

*Materials used in the production process and measurement of sound intensity*



**Fonte Sonora**  
**P = 100 W RMS**



**Fita métrica milimetrada**  
**Comprimento 50 m**



**Decibelímetro com faixa**  
**de 30 a 130 dB de medição**

Source: Authors.

Because these are measures that are difficult to carry out, since they are influenced by various environmental factors, some care was taken to try not to compromise the results, and consequently, the conclusions. We chose the time between 5:00 and 6:00 in the morning because the institution is empty and the environment as quiet as possible. This measure tried to ensure that the sound recordings made by the decibel meter were only from the emitting source. The alignment of the tip of the decibel meter with the sound source was also ensured in all measurements and the height at which they were performed was respected. With this we try to reduce the differences between random errors from one measurement to another. Also, the experimenters themselves had to pay attention to their positioning to avoid acoustic barriers between the source and the receiver. **Figure 3** shows the group members performing the sound intensity measurements.

From the sets of sound intensity measurements as a function of the distance from the source for each of the three frequencies used, we performed regressions to adjust functions in the Excel Software, from the Microsoft Office 2019 package. The functions adjusted for the set of data obtained in the sound intensity record of each frequency were of two types. For the first fit we consider a logarithmic function, since the Bel scale is constructed as follows. However, because these are real data prone to experimental errors, we also chose a second adjustment as a way to reinforce the conclusions. The second regression to adjust the sound intensity data with the distance from the source was performed with linear functions. Since we do not seek to explain a specific measure, but rather the tendency of decay of these functions to compare them, there is no problem in using different mathematical models assuming that the theoretical premises are not known.

**Figure 3**

*Group members performing sound intensity measurements*



Source: Authors.

With the two functions adjusted, logarithmic and linear, for each of the frequencies, we applied a differential calculation tool to determine which one suffered a more intense rate of change. We performed the derivatives of these functions of sound intensity with distance to determine who suffered a faster decay, and consequently, a greater sound attenuation.

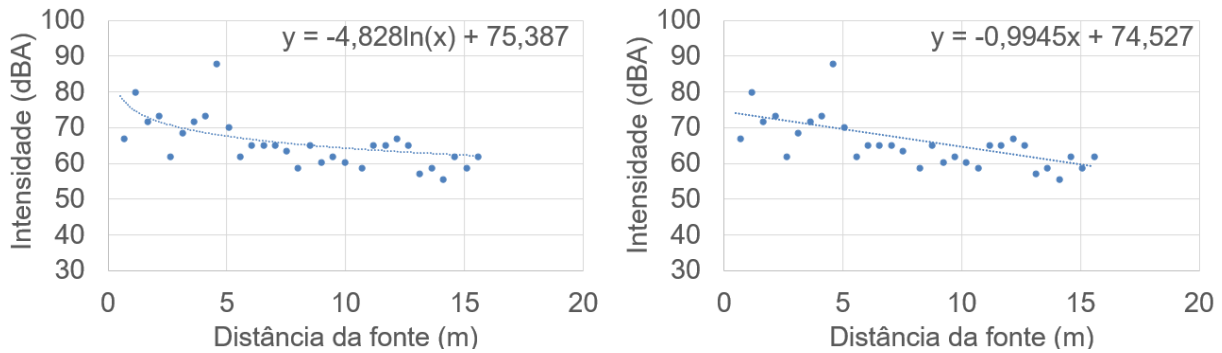
#### **4 RESULTS AND DISCUSSION**

In this section we will present the results produced from the use of the described methodology and the data obtained. Figures 4, 5 and 6 present side by side the logarithmic and linear adjustments for each of the three frequencies used, respectively.

**Figure 4**

*Adjustment of the logarithmic and linear functions as a function of distance from the source.*

*Frequency of 400 Hertz*

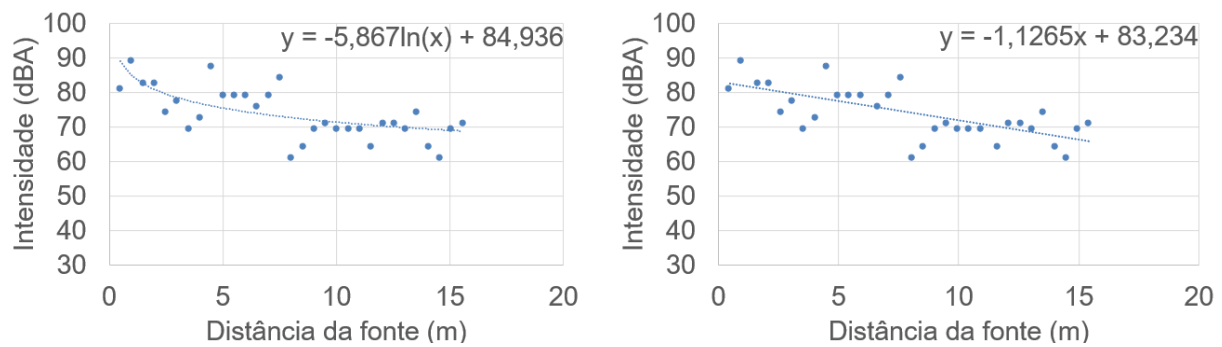


Source: Authors.

**Figure 5**

*Adjustment of logarithmic and linear functions as a function of distance from the source.*

*Frequency of 1600 Hertz*

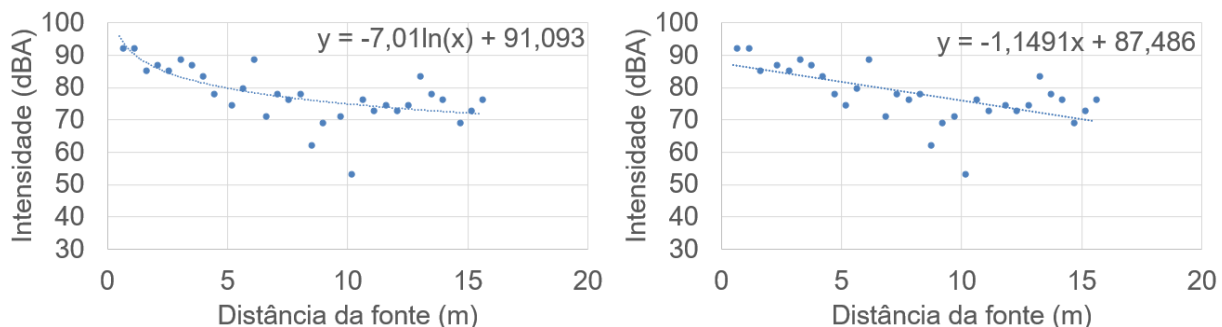


Source: Authors.

**Figure 6**

*Adjustment of logarithmic and linear functions as a function of distance from the source.*

*Frequency of 3200 Hertz*



Source: Authors.

The following table contains the logarithmic and linear functions fitted for each of the three frequencies that have been tuned. Their respective derivatives are also presented to show the decrease of the adjusted functions.

**Table 1**

*Set of adjusted functions and their derivatives for each of the frequencies.*

Frequency (Hz)	Derived from logarithmic functions	Derived from the functions linear
400	$-4,828/x$	$-0,9945$
1600	$-5,867/x$	$-1,1265$
3200	$-7,010/x$	$-1,1491$

Source: Authors.

As can be seen in **Figures 4, 5 and 6**, the measurements are quite far from the adjusted functions, showing that individual points are not well explained by them. Above all, linear functions seem to have a level of determination that differs little from logarithmic functions. This result shows that, although the Bel scale used by the decibel meter is mathematically constructed as logarithmic, the high error inherent in the experimental data hides its nature and makes another function fit with similar reasonableness. This high level of error obtained in the adjustments of the curves shows that, although the measurements were taken before dawn when, theoretically, it is quieter, the fact of being in the metropolitan region greatly affects this type of measurement due to the level of noise pollution as presented in Bressane *et al.* (2010). Above all, because the IFRJ, Rio de Janeiro Campus, is next to a busy road, Avenida Rei Pelé. In addition to the results intrinsic to this work, this discussion shows that the academic environment of IFRJ, Campus Rio de Janeiro has a high level of noise pollution.

However, although the adjusted curves do not present a good description of the individual points, more important than each isolated measurement is the trend of the set. In this sense, some previous statements can be made. Among them is that there is degradation of sound energy depending on the frequency of the sound. This verification can be carried out since all the measurements were produced strictly under the same conditions, and even so, it can be seen, looking at the derivatives of the logarithmic functions of the three frequencies used, that they are different. This fact is more easily perceived through the derivatives of linear fits, which correspond to the angular coefficients of the lines, which, in this case, are different.

## 5 FINAL CONSIDERATIONS

The most important conclusion of this work, which can be verified from the analysis of the results and discussions presented, is that higher frequency sound waves, that is, the higher ones, are more strongly attenuated than the lower frequency sound waves, or the lower sounds. This verification can be done by analyzing, together, the derivatives of

logarithmic functions. It can be seen that the derivative of the function adjusted for the frequency of 3200 Hz decays faster than the derivative of the function adjusted for the frequency of 1600 Hz, which, in turn, decays faster than that of 400 Hz. Higher sounds have a faster decay than lower sounds, clearly presented by the derivatives of linear functions that correspond to the slope of the lines themselves. In other words, the main conclusion that can be drawn from the results presented here is that: considering the same sound source always emitting with the same power, bass sounds can be recorded more easily at greater distances.

## ACKNOWLEDGMENTS

We sincerely thank everyone who contributed to the realization of this work dedicated to the study of the attenuation of sound waves at different frequencies. This experience was remarkable in our academic career, allowing us to investigate a relevant topic for the understanding of physical bases and their applications in everyday life.

During the research, we had the opportunity to improve our scientific skills in experimental methods, carry out research and analyze results, always guided by the challenge of understanding how sound waves behave in the face of various obstacles and environments. Each step, from a theoretical review on sound propagation to the realization of attenuation experiments, brought essential learnings about data analysis, interpretation of results, and teamwork.

We sincerely thank the institution that allowed us to carry out this study, providing fundamental resources and infrastructure for the development of the research. We also recognize the support of colleagues and collaborators, whose suggestions and encouragement were indispensable for the success of the project.

Finally, we express our gratitude for being able to participate in a scientific initiation that values student protagonism and encourages interest in topics that unite theoretical knowledge and experimental practice, preparing us for future academic and professional challenges.

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