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UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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"Optimization of the performance of acoustic screens based on Sonic Crystals"

TRABAJO FINAL DE GRADO

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Optimization of the performance of acoustic screens based on sonic crystals

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GRATITUDE

First of all, I would like to start my thesis saying thank you to all the people that unconditionally believe in me and supported me all the time during my Bachelor.

I feel so grateful to have around me an incredible family, this Bachelor thesis is not only for me, it is also for all of you, it would have been impossible without your help and motivation, I can say that I have the best family group "El Clan De Los Gafas".

For all my professors during my degree in Spain, in particular to my professor Mª José Canet Sabiela, for helping me with everything I needed and for being one of the best teacher I have ever had.

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To all my friends, my Erasmus family, and of course to my parents and my sister for supporting me and lifting me up whenever I need it. This is for you.

"There are two types of people who will tell you that you cannot make a difference in this world: those who are afraid to try and those who are afraid you will succeed"

ABSTRACT

The purpose of the present work is to explore the applicability of sonic crystals as acoustic screens in order to reduce the traffic noise in open spaces. For that purpose, a Multiple Scattering algorithm is used in combination with an evolutionary algorithm in order to optimize the performance of such structures.

KEYWORDS

- Sonic Crystals
- Band Gap
- Genetic algorithm
- Insertion Loss
- Traffic noise

ZUSAMMENFASSUNG

Der Zweck dieses Projektes ist die Reduktion von Verkehrslärm auf offenen Flächen mit Hilfe der Anwendung von Sonic Crystals als Schalldämmschicht. Aus diesem Grund wird ein Algorithmus der Mehrfachstreuung in Kombination mit einem evolutionären Algorithmus verwendet, um eine Leistungsoptimierung in solchen Strukturen zu erreichen.

STICHWÖRTER

- Schallkristallen
- Bandlücke
- Genetischer Algorithmus
- Einfügungsdämpfung
- Verkehrslärm

CONTENTS

CHAPTER I– INTRODUCTION AND HISTORIC PART

We must put this end of degree work naming Eusebio Sempere, born April 3, 1923 (Wikipedia, 2017). He was a Spanish sculptor, painter and graphic artist, one of the most representative painters of the kinetic movement in Spain, his country of origin. The lines of his works, their repetition and his mastery of color managed to make the light vibrate and gave a depth to his artistic compositions.

After a long career in the world of art, in the 1971 Eusebio Sampere made one of the works that unwittingly change the perception and opened new lines of order in the field of acoustics, after creating his sculpture located in Madrid (Spain), the sculpture is a composition of metallic cylinders as shown in the figure.

Illustration 1- One of the works of Eusebio Sampere, here we can observe the Sonic Crystals. (Sempere).

The first experimental measurement of sound attenuation by Sonic crystals was made by Martinez-Sala and other researchers of the University (UPV) in 1996, when a scientist article was published in the recognized magazine Nature (Martinez-Sala, 1996). The Sonic crystal was an artistic creation of Eusebio Sempere in Madrid, which consisted of a regular iron cylinder series as shown in Illustration 1.

Experimental tests on this sculpture showed that there was a significant sound attenuation (~ 15 dB) at 1.67 kHz. This seminal work led to further investigation of the acoustic wave passing over periodic structures. Such structures are called "Sonic Crystals" (SC) or "Phonic Crystals".

Photonic crystals generally refer to structures made of similar host and disperser material, such as nickel cylinders embedded in the copper matrix etc., while the sonic crystal refers to the structure made of dissimilar materials, such as Steel cylinders in water etc. They are for propagation of elastic waves that have longitudinal components and transverse waves; While in the sonic crystal we only consider the component of longitudinal wave, we know that a longitudinal wave is the motion of the particles is parallel to the direction of propagation of the wave.

Later on we will explain in detail what a Sonic crystal is and the physical behavior it has, we will now proceed to explain the motivation and purpose of our bachelor thesis.

1.1 MOTIVATION

One of the main aspects that I led me to choose this subject as a proposal for the Bachelor thesis was that the sound attenuation is a very important acoustics aspect and it is present in numerous situations of our daily life, as it is in the case of our project, in which we will study the attenuations of traffic noise in open spaces. One of the great benefits we can observe from the sonic crystal is that it can attenuate the sound significantly in a particular band or frequency range. Due to its selective attenuation property, it can be useful for the design of frequency filters. More ahead we will make a brief comparison between the advantages of the sonic crystals and the conventional acoustic screens, since one of the conventional methods consists in using a separation or solid barrier.

But in the SC the sound attenuation is due to the interaction of the wave with the periodic structure of the sonic crystals. SC have the advantage, compared to conventional acoustic screens, not to offer as much resistance to the wind, so they are more suitable in windy environments. Therefore, this structure can be used when simultaneous acoustic insulation and heat transfer are required. Therefore, developing numerical models for the propagation of sound in the sonic crystals can help solve more complicated problems that may arise in the future.

1.2 OBJECTIVE

Like I said earlier, the purpose of the present work is to explore the applicability of sonic crystals as acoustic screens in order to reduce the traffic noise in open spaces. For that purpose, a Multiple Scattering algorithm is used in combination with an evolutionary algorithm in order to optimize the performance of such structures.

We know that when the waves propagate in a medium with dispersive materials which are placed periodically, this leads us to a phenomenon that is called the band structure, as it happens in the CS. This means that there will be a range of frequencies in which the wave will be propagated (Following the rules of dispersion), but there will be other frequency ranges that will be eliminated. These are called BAND GAP. Therefore, to predict the "insulating" behavior of the SC we use a code based on Multiple scattering, a more than contrasted Simulation method.

We will study which range of frequencies are most appropriate, for that we will analyze the most relevant frequencies in traffic noise, and once we select the most effective frequency ranges of our sonic crystals, we will use a code based on evolutionary algorithms called evMOGA. Evolutionary algorithms are methods of optimization and research for solutions based on the postulates of biological evolution.

They maintain a set of entities that represent possible solutions, which mix and compete with each other, so that the most apt are able to prevail over time, evolving towards better solutions each time.

In order to begin the development of our work we must explain the behavior of a sound wave and introduce some basic physics aspects.

CHAPTER 2– PHYSICAL PHENOMENAL

2.1 SOUND WAVES

A sound is a physical phenomenon consisting of the mechanical alteration of the particles of an elastic medium, produced by a vibrating element, which is capable of provoking an auditory sensation. The vibrations are transmitted in the medium, usually the air, in the form of sound waves. They are introduced into the outer ear by entering the pavilion of our ear, where at its end we find the membrane of the tympanum, and they make it vibrate.

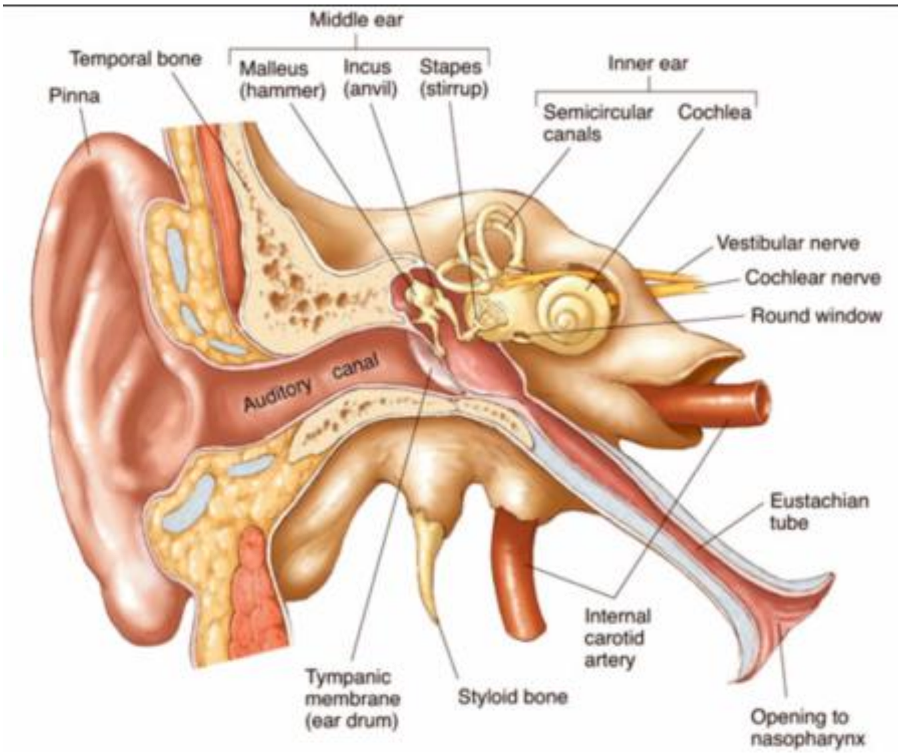


Illustration 2- Ear Structure (Biologyboom, 2017)

In the air, which is the medium we will usually refer to, the phenomenon is propagated by the vibration of the air molecules located in the vicinity of the vibrating element, which in turn transmits the movement to the neighboring molecules, and thus successively. The vibration of the air molecules causes a variation of the atmospheric pressure; therefore, the passage of a sound wave produces a pressure wave that is propagated by the air. The propagation speed in this medium, under normal conditions of temperature and pressure, is approximately 340 m / s.

This pressure variation is called acoustic pressure or sound pressure, and is defined as the difference at a given instant between instantaneous pressure and atmospheric pressure. The acoustic pressure varies very sharply over time; These abrupt variations are perceived by the human ear, creating the auditory sensation. Sound waves are attenuated with distance and they can be absorbed or reflected by the obstacles they encounter in their path.

There are two types of sound waves, depending on how the particles move in the medium:

1. Longitudinal waves: When the movement of the particles is parallel to the propagation of the wave
2. Transverse waves: When the movement of the particles is perpendicular to the propagation of the wave.

2.2 CHARACTERISTICS OF THE SOUND WAVES

Let's make a brief explanation about the most relevant characteristics of sound waves that we all should know; these parameters that we will show in detail below are the characteristics that determine our sound wave:

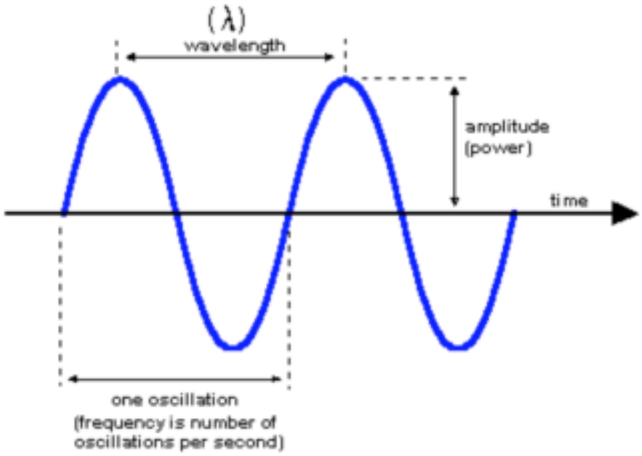


Illustration 3- Sound Wave (Computer Desktop Encyclopedia, 1981)

- Amplitude: It is the difference between the maximum and minimum values of the wave motion at a point. It represents the variation of pressure existing at that point.

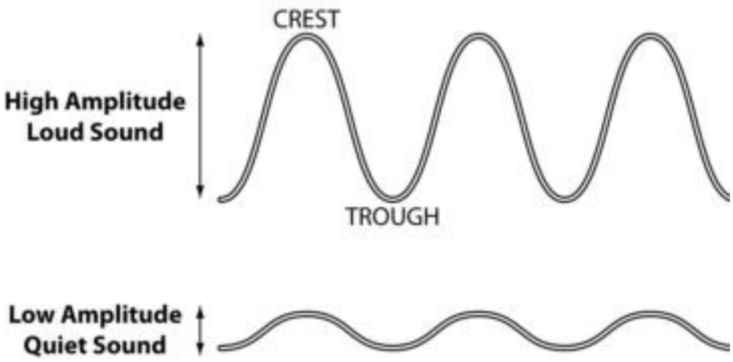


Illustration 4- Amplitude (smugmug, 2017)

- Frequency (f): Is the number of times that a (periodic) phenomenon repeats itself per second. It is the inverse of the period of repetition (T). It is measured in Hertz (Hz), which represents the number of oscillations per second.

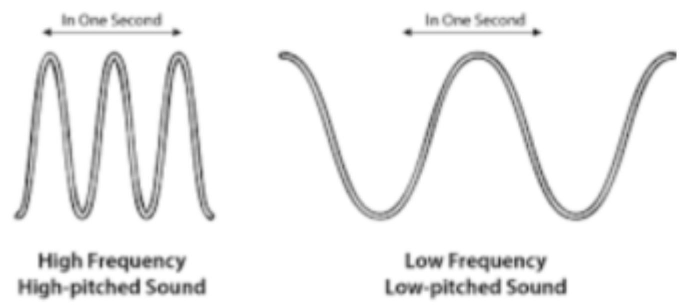


Illustration 5- Frequency

- Speed of the sound (v): It is the speed at which the sound wave travels. It depends on the medium where it is propagating and on the temperature.

    - We know that the speed depends on the frequency and the wavelength of the wave:

        - $v = f * \lambda$ [1]

- Wavelength (λ): It is the perpendicular distance between two wave fronts that have the same phase. This length is the same as the one covered by the wave in a complete cycle of vibration.

[1] Speed of the sound equation

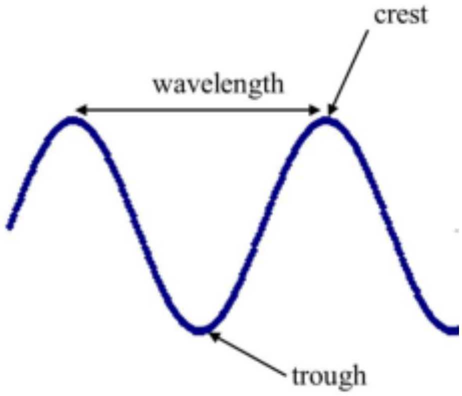


Illustration 6- Wavelength

- Period (T): It is the time it takes the wave to perform a full vibration, it is the minimum unit of the wave that, when repeated, forms the complete wave. The period is measured in seconds, and it is the inverse of the frequency, which means that if we wanted to know the frequency of a wave and we have the data of the period we have to do the inverse (1 / f).

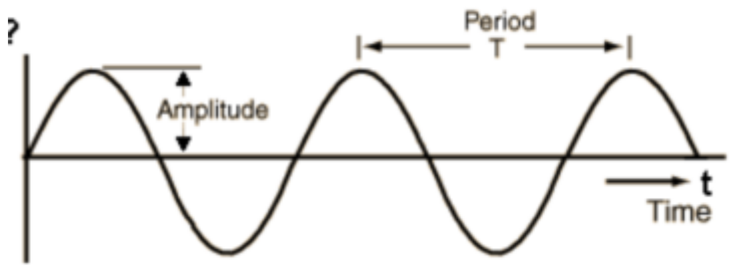


Illustration 7- Period

2.3 PHYSICAL SOUND EFFECTS

Now we will explain the different behaviors that a sound wave can have to the impactor with a surface.

We know that when a sound source emits energy, the sound waves produced propagate radially in all directions from it, and when an obstacle is encountered, namely, a surface changes in its direction.

Reflection and sound diffraction:

- Reflection: it occurs when a wave is propagated and it hits an obstacle, which causes some of the acoustic energy to return. If the surface of this obstacle is smooth and large enough, a single-direction reflection will occur following Snell's law, namely, the reflected angle r is equal to the incident angle i (Pörschmann, 2016).

    - Snell Law:

$$n_1 \sin\theta = n_2 \sin\theta$$ [2]

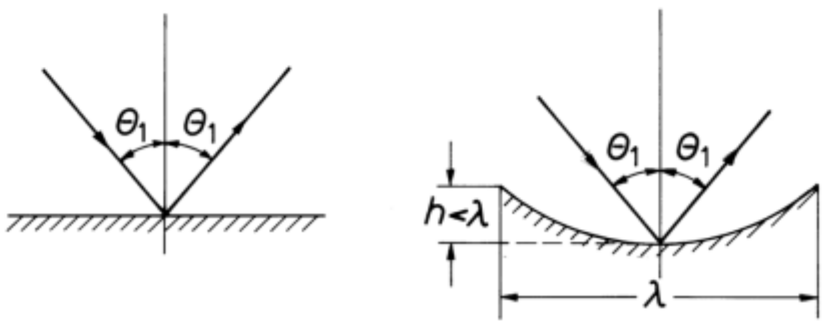


Illustration 8- Reflection on a flat surface (Blauert and Xiang, Acoustic for Engineers, 2008)

[2] Snell equation

Also we must know that the wave has different behaviors, due to the shape of the surface, we can differentiate between concave surfaces and convex surfaces:

- Concave surface:

- Convex surface:

We are going to show the different behavior that the wave has when it propagates trough concave or convex surface, the surfaces of a room are not flat, but slightly curved, so scattering or focusing of sound can occur. This is in a specific surface:

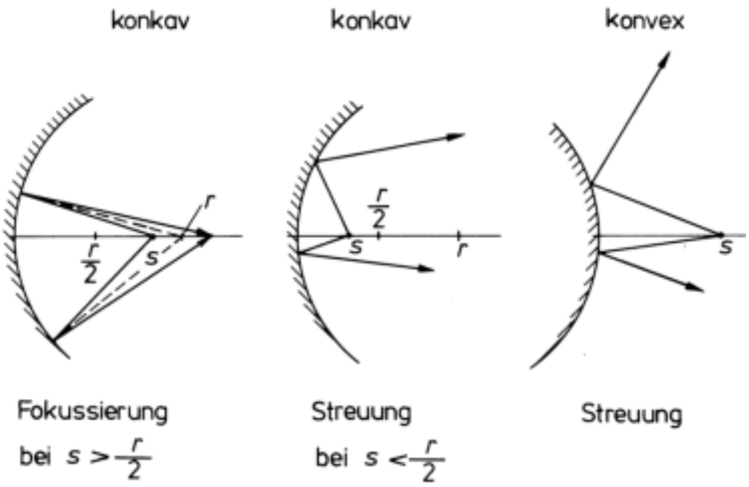


Illustration 9- Focusing and scattering of sound when impacting a curved surface (Blauert and Xiang, Acoustics for Engineers, 2008)

When we can assume that the dimensions of the enclosures are not large enough compared to the wavelength of the sound, we can treat this problem in the same way as when the light is analyzed by means of geometric acoustics, as we have observed in the previous graphs.

An example of how to study the behavior of waves when they incident on a surface and to study their path after reflection is to use ray tracing methods. This technique is often used to detect problems in large venues such as theaters or concert halls. But we must take into account that for wavelengths of orders of magnitude similar to the dimensions of the premises, the modes of reckoning that are produced to perform an elaborate study must be analyzed (Blauert and Xiang, Acoustic for Engineers, 2008).

But nevertheless, we must know that this is not always the behavior of the sound wave when it hits a surface, if the dimensions of the obstacle are not large, there will be another wave that will propagate by passing it in the same direction of incidence. This phenomenon, in which the sound surrounds the sufficiently small obstacles, is denominated diffraction. The effects of diffraction decrease until they become undetectable as the size of the obstacle increases compared to the wavelength.

We must know that this depends on the frequency, since we know that the wavelength is inversely proportional to the frequency:

$$\lambda = \frac{c}{f}$$ [3]

Is denominated diffraction of a wave to the property that the waves have to surround the obstacles in certain conditions. When a wave arrives at an obstacle (aperture or material point) of dimensions similar to its wavelength, it becomes a new source emitting the wave.

This means that when a wave arrives at an obstacle of dimension similar to the wavelength, that obstacle becomes a new focus emitter of the wave. The more similar the wavelength to the greater obstacle is the diffraction phenomenon.

Here we are going to show one example about the diffraction effects:

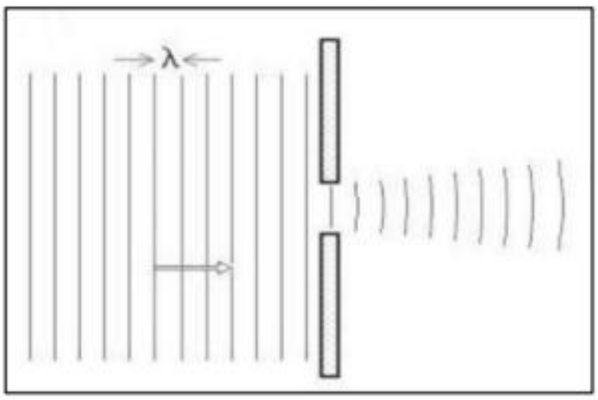


Illustration 10- Diffraction effect

[3] Wavelength equation

We explain these behaviors of a sound wave, because when a sound wave hits a wall, it has different compartments according to the characteristics of the wall, in our case as we said above, we will also proceed to make a comparison between the sonic crystals and the acoustic screens, and it is convenient to explain this because we can find this type of effects in the acoustic barriers and also in the SC.

CHAPTER 3– NOISE

To start talking about noise, we must explain what it is or what noise is considered, we must take into account that finding an exact definition of what we perceive as noise is not easy, but we could define the noise as "it is all unwanted sound ", Especially to define the noise as an annoying or unwanted sound, we must first define what we mean by sound.

Sound is that auditory affection produced by a vibration of air characterized by a periodic sequence in time and in the absence of expansions and compressions.

If we rely on:

Royal Decree 1909/1981, of July 24, (Agencia Estatal BOLETÍN OFICIAL DEL ESTADO, 1981) *approving the Basic Regulation of Building NBE-CA-81 (currently NBE-CA-88) on acoustic conditions in buildings defines sound as "sensation Sound produced by an acoustic wave. Any complex sound can be considered as a result of the diction of several sounds produced by simultaneous sinusoidal waves "*

The NBE-CA-81, referred to above, specifies in Annex 1 a definition of noise as "a complex mixture of sounds with different fundamental frequencies". In a broad sense, any sound that interferes with some human activity can be considered noise.

Therefore, we can observe that there is a certain complexity in being able to accurately describe what noise is. These definitions exposed before, although they can be more scientific and rigorous, can be summed up in the concept that supposes the noise like annoying or unwanted sound. This is the reason, as we said at the beginning, why we will take the noise as the unwanted sound.

This is the most general criterion, within which the rest of the definitions are subsumed. Thus it has also been defined as an "Excessive or untimely sound or, more precisely, as any sound capable of producing physiological or psychological effects on a person or group of people"

3.1 NOISE IN OUR SOCIETY

Once we have given a definition of noise and we can get to understand what it is, we must know that it is one of the most relevant environmental problems in our era. Its undoubted social dimension contributes to a great extent to it, since the sources that produce it are part of the daily life: activities and places of leisure, means of transport, industrial activities, etc.

It is one of the major concerns of the current population, since it is present in practically 100% of our daily life, that is why it has a great weight in labor legislation and is becoming more present in the population in general. In recent years there are numerous judgments that recognize noise as a health risk factor and the labor law recognizes hearing loss or deafness as a work accident caused by noise (EPA, 1974).

Once explained what noise is, and the importance that it has both for the human being and in environmental problems, we must explain as we measure the noise in order to successively explain the types of noise that we are going to find, and thus later to focus on the noise of traffic that is the type of noise that we are going to treat in our thesis.

3.2 PARAMETERS OF THE NOISE

We will talk about the parameters that define the noise, since at the moment of making measurements and obtaining good ratings, we must know which parameters we should evaluate for it.

Here again we will explain the wave parameters of the wave, but we have already explained them in the section characteristic of sound waves, Therefore, we are going to explain the parameters that have not been explained previously but are necessary in the noise.

Now we will proceed to explain other parameters, which are relevant when we refer to the noise and that are important to keep in mind, for a good evaluation of it.

We will begin to define concepts necessary for noise:

- Tone: It is a property that all the sounds have; it characterizes and differentiates among them as more low-pitched or more high-pitched, depending on its frequency. The variation of pressure depends on a single frequency, although we know that the real sounds are composed of several tones.
    - Low-pitched Tones: Approximately go from 16 Hz to 256 Hz.
    - Medium-pitched Tones: Approximately go from 256 Hz to 2 kHz.
    - High-pitched Tones: Approximately go from 2 kHz to 16 kHz.

- Sound pressure: It is product of the own propagation of the sound. The energy generated by the sound waves generates an ondulatory movement of the particles of the air, provoking the alternate variation in the static pressure of the air (small variations in the atmospheric pressure).

Therefore, the acoustic pressure is defined as the instantaneous pressure difference (when the sound wave reaches the ear) and the static atmospheric pressure.

We know that a healthy young ear is sensitive to frequencies between 20 Hz and 20 kHz; the audible spectrum we humans have, is divided into 11 octaves, and one octave is the interval between sounds that have a relation of Frequencies equal to 1: 2 (the maximum value of the frequencies of each octave is the double of the previous one).

In order to be able to carry out noise analysis and measurements, the bands of octave or bands of third of octave (1/3 octave) are used in our case; for example, we will use 1/3 octave bands.

For octave bands with center f, the upper(fs) and lower (fi) f values are:

- $fs = f * \sqrt{2}$ y $fi = \frac{f}{\sqrt{2}}$, that is:
- $\frac{fs}{fi} = 2$ [4]

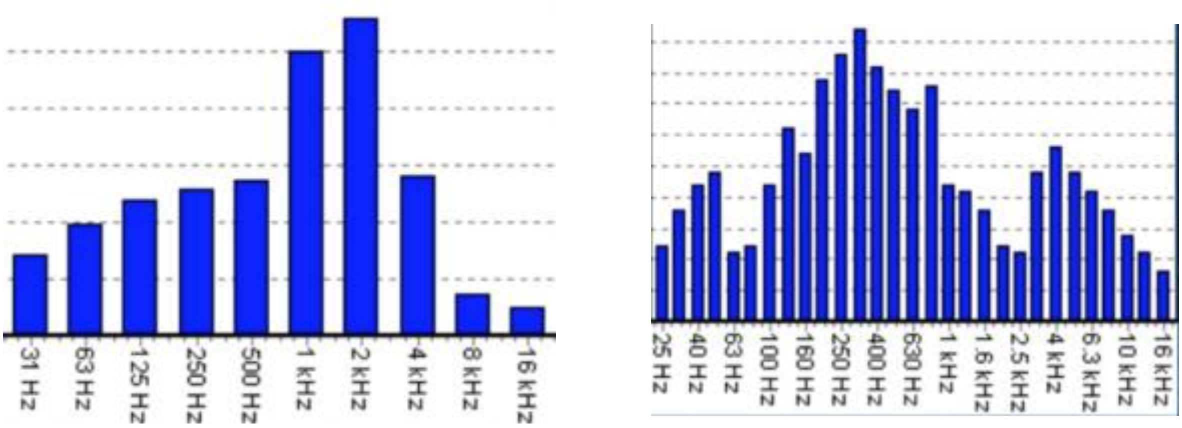


Illustration 11- Range of octave and one third octave bands of frequencies

[4] Octave bands frequencies equation

The field of hearing as stated above is defined as 20 Hz and 20 kHz, but there is another limitation determined by the sound pressure, this threshold of perception is between 20µPa (Threshold of hearing) and 20Pa (Threshold of pain), which implies a scale of millions of units.

To introduce the measurement of noise we must start by talking about one of the norms that regulate the noise, we speak of *ISO standard 1999: 1990* (Standardization) the level of exposure of the noise, $L_{EX,8h}$, as fundamental quantity to describe the noise intensity. It originates at the sound pressure level Lp, defined by the equation:

- $L_p = 10\log\left(\frac{P}{Po}\right)^2$ [5]

Where:

- P is the sound pressure, or the difference between the instantaneous pressure and the static atmospheric pressure.
- Po is the reference pressure, which is equal to 20uPa.

We know that in the sound pressure level is expressed in dB, a logarithmic expression is used, but this is due to how it happens most of the time when expressing a system in logarithmic, since it allows to compress a much wider range than if it were linear, the way to express it with fewer orders of magnitude from 0 dB to 160 dB.

The sound pressure level is one of the most common results of measurement equipment, as well as one of the most reflected parameters when you set permissible levels in the legislation.

[5] Sound presure level equation

3.4 SOUND LEVEL

A noise is perceived with greater or less intensity depending on two fundamental physical factors:

- Sound pressure level.
- Frequency

The following figure shows the results of a psychoacoustical experiment averaged over a large number of subjects. The test persons had to find a setting for two signals of different frequencies (sinusoidal or narrow-band noise) so that the two signals were perceived exactly the same. On the basis of the results of this experiment the volume level LN (in phon) was defined. It indicates how loud a sound is perceived by a person.

The volume level is normalized to the frequency of 1000 Hz. This means that at this frequency the sound pressure level and the loudness level have the same numerical value (Eberhard Zwicker, 1990).

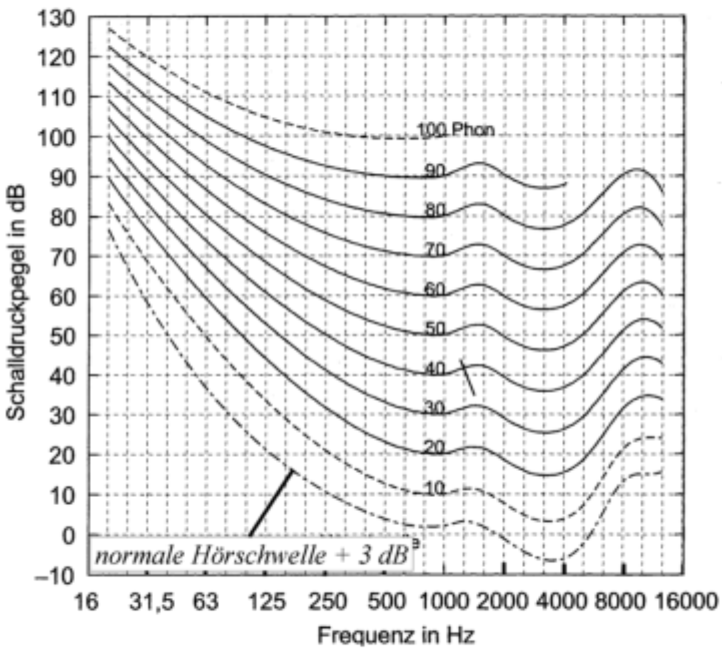


Illustration 12- Diagram of loudness (Pörschmann, 2016)

Relationship between sound pressure level and loudness level (in phon). The diagram shows the curves of the same loudness (isophones) (ISO 226 / DIN 45630, for binaural hearing in the sound field in frontal incidence).

In order to try to approximate the acoustic analyzers to the ear response, we created the frequency weighting curves. These are a simplification of the frequency response of the ear at different levels. That is why we use the weights A, B and C.

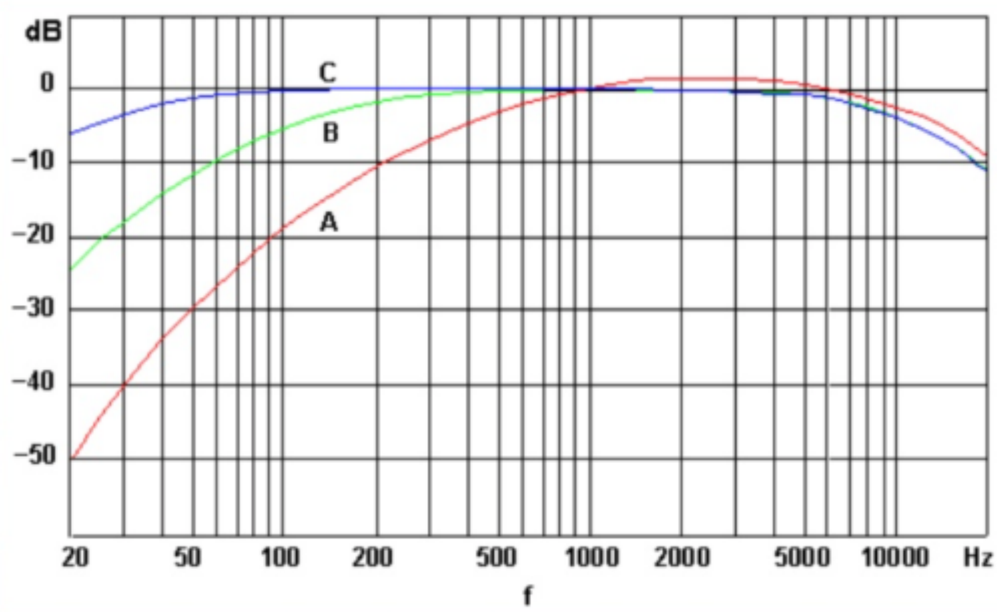


Illustration 13- Different values of (A,B,C)-weighted

- The A-weighted scale is thought of as attenuation similar to that of the human ear when it supports low sound pressure levels at different frequencies.
- The B scale is practically not used.
- The C scale represents the attenuation for high levels (punctual events are measured; it is almost linear).

The loudness is a subjective characteristic, measured as the sensation produced by certain variations of pressure in the ear.

The behavior of the human ear is closer to a logarithmic function than to a linear one. A human ear is able to perceive and support sounds corresponding to sound pressure levels between 0 and 120 dB. This last level of noise marks the so-called "pain threshold". Higher noise levels can cause physical damage such as rupturing the eardrum.

3.5 TYPES OF NOISE

In our daily lives we often perceive noises, coming from various systems such as ventilation or heating, or from any appliance, which we hardly pay attention to, since they have no remarkable characteristics. Those noises never stop and do not have Tone, but if for any reason those noises stop or make some extravagant sound, they could attract attention and even get to bother. Our ear recognizes information in the sounds we hear, the information that we do not need or do not want, become noise.

The characteristics of the noise that make us stop and pay attention, are the tones or changes of sound level, the more noticeable is the noise.

When we measure noise, we need to know the type of noise it is, so that we can select the parameters to measure, the equipment to use, and the necessary duration of the measurements. Often we have to use our ear to capture and emphasize the annoying characteristics of noise, before we start taking measurements, analyzing them and documenting them.

That is why we will begin to explain the types of noise that exist and that we can find in our day to day:

- Continuous noise

  This type of noise is produced by a machinery that operates in the same mode without interruption, whose intensity remains constant or has fluctuations (less than 5 decibels) over time. Such as, for example, fans, pumps and process equipment. In this case for determining the noise level it is sufficient to measure for a few minutes with a manual equipment.

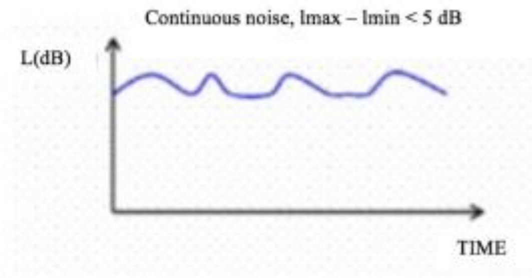


Illustration 14- Continuous noise

- <u>Intermittent noise</u>

  In this case it is produced when the machinery operates in cycles, or when isolated vehicles or airplanes are passing by, the noise level increases and decreases quickly. For each cycle of a noise of machinery noise, the noise level can be measured simply as a noise. The isolated step of a vehicle or aircraft is called event. To measure the noise of an event, the level of sound exposure is measured, combining in a single descriptor both the level and the maximum sound pressure level, which can also be used. A similar number of events can be measured to establish a reliable mean.

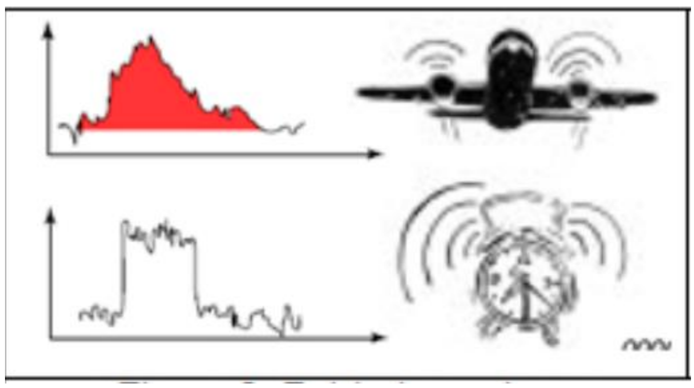


Illustration 15- Intermittent noise

- <u>Impulsive noise</u>

  Noise from impacts or explosions, for example from a hammer, a die cutter or a pistol, is called impulsive noise. It is brief and abrupt, and it's surprising effect causes greater annoyance than expected from a simple measurement of the sound pressure level. To quantify the noise impulse, the difference between a fast response parameter and a slow response parameter (as seen at the bottom of the graph) can be used. The repetition rate of the pulses (number of pulses per second, minute, hour or day) must also be documented.

Impulse noise is also characterized by a sudden rise in noise in less than 35 milliseconds and a total duration of less than 500 milliseconds. The time elapsed between crests must be equal to or greater than one second.

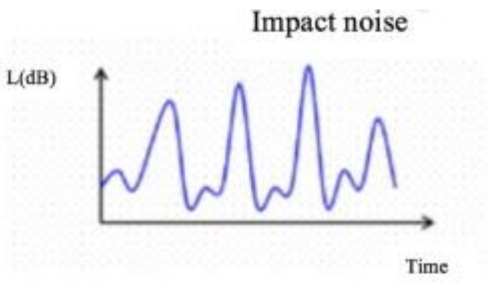


Illustration 16- Impact noise

- <u>Tonal noise</u>
  Often in rotating machines, such as motors, gearboxes, fans and pumps, there are repeated imbalances or impacts causing vibrations that, transmitted to the air, can be heard as tones. Tones can also generate pulsating flows of liquids or gases that occur because of combustion processes or flow restrictions. These tones can be identified subjectively by listening to them, or objectively, by frequency analysis, comparing the tone level to the level of the surrounding spectral components.


Illustration 17- Tonal noise

- <u>Low-frequency noise</u>

  Low-frequency noise has a significant acoustic energy in the frequency range of 8 to 100 Hz. This type of noise is typical for large diesel engines of trains, ships and power plants and since this noise is difficult to damp and stretches easily in all directions, it can be heard for many kilometers. Low-frequency noise is more troublesome than what one would expect with a measure of the A-weighted sound pressure level. The difference between the A-weighted sound level and the C-weighted sound level may indicate the existence or not of a low noise problem frequency.

  To calculate the audibility of low frequency components in noise, the spectrum is measured and compared to the auditory threshold. Infrasound has a spectrum with significant components below 20 Hz. We perceive it not as a sound but rather as a pressure. The evaluation of infrasound is still experimental and is not currently reflected in international standards.

Illustration 18- Low frequency low

The following noises are used to carry out the standard measures:

• <u>White noise</u>

It contains all frequencies with the same amplitude. It is a pattern noise that is characterized by a 3dB increase in sound pressure each time the octave band increases.

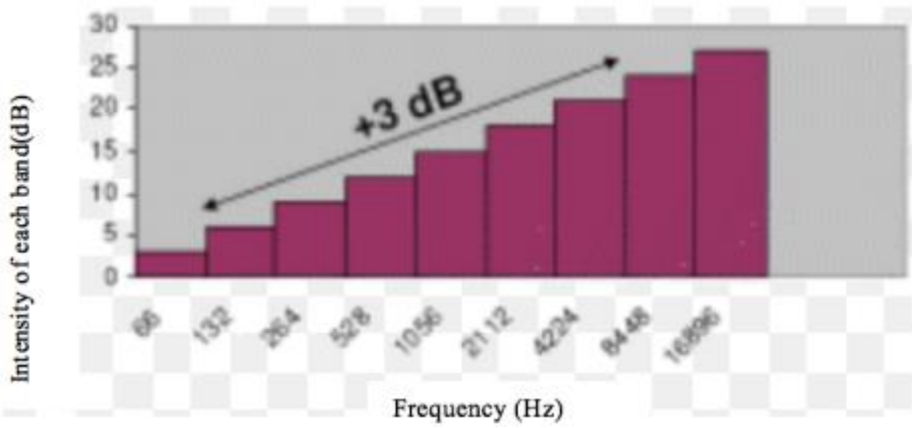


Illustration 19- White noise

- Pink noise

  it is a noise whose sound level is constant in all octave bands. It is the one used in isolation and laboratory measurements. It is a pattern noise that is characterized by a decrease of 3dB in sound pressure each time the octave band increases.

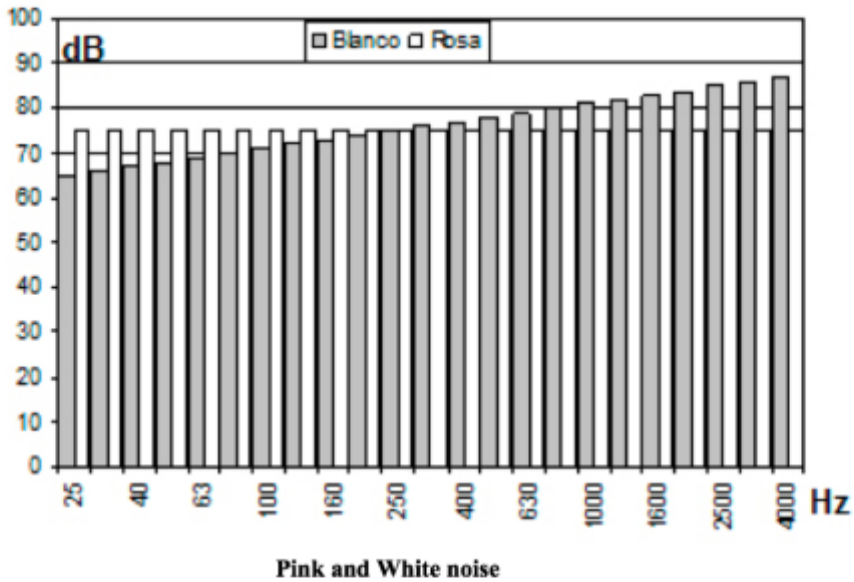


Illustration 20- Pink noise

• Traffic noise:

In the next point we are going to explain with more details this kind of traffic.

3.6 TRAFFIC NOISE

After making a description of the different types of noise we can find, we will dedicate this section to talk about traffic noise as our thesis is based on “exploring the applicability of sonic crystals as acoustic screens in order to reduce the traffic noise in open spaces”.

Since noise is a byproduct of human activity, its most important manifestation occurs in places where such activities are concentrated, mainly in industries and workplaces and, in general, in large cities. Nowadays the main sound objects that constitute the acoustic medium in urban areas are related to the means of transport of people and goods. In qualitative terms, this conclusion can be extended also to the rural milieu. This category of sound sources is constituted by three types of vehicles mainly: automobiles, airplanes and railroads.

Undoubtedly, the most important sources of noise in industrialized countries are cars (cars, trucks, buses, motorcycles, etc.). In particular, wheeled circulation has become in a short time the most important source of noise pollution in all the major cities in the world. This assertion is based on the dramatic increase in the number of vehicles over the last few years and on the fact that the cities in which it is happening, have not been designed to support it (note that, taken individually, vehicles are not an overly noisy sound source).

Spectral levels and composition of traffic noise vary considerably depending on numerous parameters. These noises, in fact, depend on the types of vehicles that generate them, on the conditions of use, on the transported cargo. In any case, the most important parameter is the traffic intensity. The conditions of the corresponding infrastructures (nature and state of the firm, traffic regulation, urban structure, etc.) also play a significant role.

In an ordinary car, sound sources are very diverse: engine bursts, intake noises, brakes, body vibrations and, finally, the noise produced by the displacement of the tires on the lining of the road. We must bear in mind that one of the latest reports obtained by the European Environments Agency tells us that (European Environment):

"*Environmental noise - unwanted or harmful external noise - is increasingly widespread, both in terms of its duration and geographic coverage. Noise is associated with numerous human activities, but the noisiest are railway traffic, road traffic and air traffic. It is a problem that especially affects the urban environment; About 75% of the European population lives in cities, and traffic volumes continue to increase. In many European countries, city studies show that the number of complaints related to environmental noise is increasing.*

Since environmental noise is persistent and unavoidable, a significant part of the population is exposed to it. The EU Green Paper on future noise policy states that around 20% of the EU population suffers from noise levels which health experts consider unacceptable, i.e., they can cause discomfort, sleep disturbances and harmful effects on health. The World Health Organization (WHO) estimates that about 40% of the EU population is exposed to traffic noise levels in excess of 55 dB (A), and that more than 30% are exposed to Levels that exceed 55 dB (A) at night. "

Even if observed from the inside the vehicles seem to us much quieter every day, the reality is that, in general, there have been no substantial improvements in the noise levels that they originate. From the technological point of view, the most important effort made by the different manufacturers in recent years has focused on reducing fuel consumption and air pollution. In fact, the reduction of consumption - a true obsession from the moment the energy crisis breaks out - has in some cases resulted in an increase in the noise level of certain models, since the reduction of engine capacity is usually accompanied by an increase in their speed regime. Although it is to be expected that major developments will be made in this sector in the coming years, any speculation in this regard is quite risky (development of new technologies, replacement of conventional cars with electric vehicles, etc.).

As we have said before, if based on the main sources, in this case a car which emits noise, we must note that, considered individually, the vehicles are not an excessively noisy sound source.

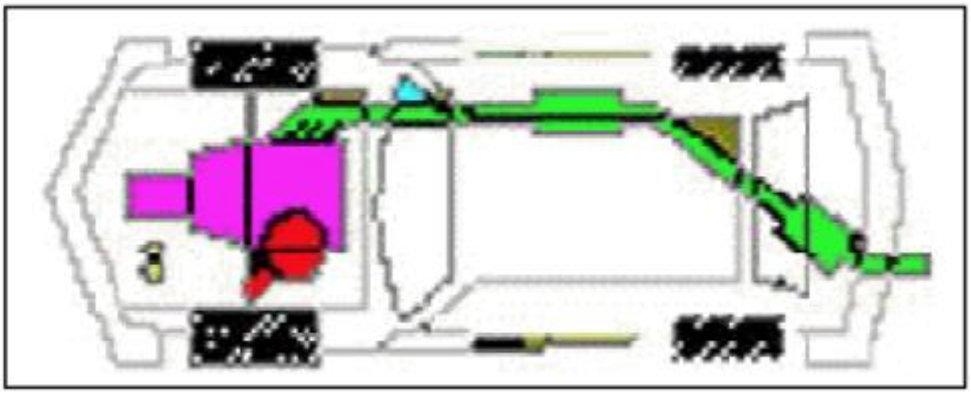


Illustration 21- Part of the car that emit noise

Unlike other environmental problems, noise pollution continues to increase and there is an increasing number of complaints from the population.

Spectral levels and composition of traffic noise vary considerably depending on numerous parameters. These noises, in fact, depend on the types of vehicles that generate them, the conditions of use, the cargo transported, etc. In any case, the most important parameter is the traffic intensity, which is why it is an essential parameter in traffic noise and we must talk about it, since traffic noise generated by a traffic channel is a sequence of simultaneous sums of the variable sound levels generated by the different vehicles that form said traffic.

The variation of the noise with the time is the main characteristic of the ambient noise in particles of the traffic noise.

We know that if the traffic intensity in a road is low, the average distance between vehicles is large and the passage of them is practically independent from the rest, with

remarkable periods of time during which the noise remains constant, or almost constant, in the background level.

As the traffic intensity increases, the average distance between vehicles decreases, and less background noise is heard. When the traffic is too high the noise is almost constant.

For intermediate traffic, there is a grouping of vehicles which causes moments, during which the background noise is not generated by the traffic of the road, while for others the sound level is higher than expected, if these groupings do not occur. This is largely due to the random nature of traffic, both in the presence of vehicles at a point on the road and in the composition of the same. This makes variations of the sound level even greater in these cases.

Due to all the above explained and to the great presence of traffic noise that we have today, we want to realize this thesis to be able to get to improve these produced levels and to use the crystals of sound as a tool for this.

In the following chapters we will explain how we will develop our project and how we can reduce these levels of intensity and sound pressure generated by traffic noise, but first we will mention the effects that noise has on the human being.

3.7 NOISE EFFECTS ON THE HUMAN BEING

As we have stated in the previous section, traffic noise is not only a problem that affects the environment, but it is also a problem that is affecting the health of the human being, we know that according to WHO.

"The World Health Organization (WHO) estimates that about 40% of the EU population are exposed to traffic noise levels in excess of 55 dB (A), and more than 30% are exposed to Levels that exceed 55 dB (A) at night. "

Therefore, it is convenient to know that noise is not only a harmful or unwanted sound, but also causes multiple negative effects on the health of the human being.
It is true that the recognition that noise is a health hazard is recent, and its effects have come to be considered an increasingly important health problem.

Now, we are going to show a little bit of cases of the negative effects on the health of the human being that the noise can create:

- Noise pollution affects both health and behavior
- Unwanted sound can damage psychological health
- Annoyance
- Aggressivity
- Hypertension
- High stress levels
- Hearing loss
- Sleep disturbances, and other harmful effects

3.8 NOISE CONTROL

The noise control is the adaptation of the noise levels to acceptable and recommendable levels.

Once determined the problems of noise suffered in an area, the control of the same can be done from 3 points of view:

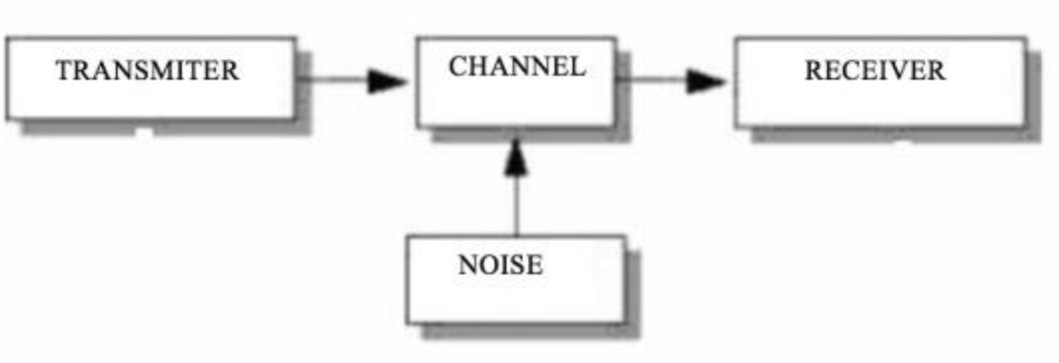


Illustration 22- The control of the noise can be done from three points of view

- In the source
- In the receptor
- In the medium of the propagation

In our case we will only focus on the noise control in the propagation, since our work is about reducing traffic noise through sonic crystals, we will explain some more common methods of noise control in propagation as they are: modification of the orientation of facades, acoustic screens or enclosures, to later describe sonic crystals, that is the object on which our investigation is based.

Sound is a wave that spreads through the air, as we well know. But this propagation is not gratuitous, since the friction that occurs between particles with the advancing of the wave, produces dissipation of energy. We can take advantage of this in order to reduce the level of sound that the listeners receive. Another form of energy is the attenuation produced by obstacles and barriers that the wave finds in its propagation.

Some methods of noise control in propagation as we have previously mentioned could be:

- <u>Modification of facade orientation:</u>

  In areas where we find a high traffic intensity and therefore a high noise level, the way to increase the distance and therefore the level of sleep received in the houses, is to place the buildings in such a way that the facade does not coincide with the layout of the road, thus reducing the noise level received in the facade.

- <u>Enclosures:</u>

  This solution consists in enclosing the source in cabins that reduce the level of emission on the exterior of the cabins themselves. These types of solutions are widely used in ventilation elements of buildings, installed on roofs, and the walls of the enclosure are usually integrated with absorbent materials.

- <u>Acoustic screens:</u>

  Let's focus more on explaining the acoustic screens, since we want to do our job, that is the simulation of acoustic screens through the sonic crystals.

We understand as a barrier or acoustic screen, a surface with a surface weight of at least 20 kg / m ^ 2, that is interposed in the trajectory of the acoustic waves, preventing its propagation partially to the other side and creating a zone of shadow.

For the determination of a building of a screen, it is necessary to relate the calculations not only for the wave between sources and receiver, but for all the possible routes of this and the possible reflections that may occur.

Mainly the acoustic panels can be of two types:

- Reflective
- Absorbent

The most frequent are the reflective acoustic screens, we can find many of them in sections of roads where we have a high traffic intensity and we have fence homes that the noise can affect.

Illustration 23- Example of acoustic screens

While the absorbers are also equipped with an acoustic absorption system of the incident wave that hinders the existence of reflection, reducing its effect. Barriers of this type generally consist of an inner reflective screen, lined with absorbent material and protected by conveniently perforated plates.

Other types of screening may be earth dams, which are obstacles of great thickness that are generally covered with soil.

One of the new methods, which we are going to speak about in this work, consists in the sonic crystals, which we will introduce in the following section, to enter into the control of the ring in the propagation of the wave.

As mentioned in the introduction, in 1971 Eusebio Sampere (Sempere) created one of the works that would inadvertently change the perception and opened new lines of investigation in the field of Acoustics, after creating his culture located in Madrid (Spain). This work is a composition of metallic cylinders, as it can be seen in the figure.

Illustration 24- One of the works of Eusebio Sampere, here we can observe the Sonic Crystals. (Sempere)

We must explain to what which we refer with sonic crystal. It is called sonic crystal (or photonic crystal) a material composed of elements arranged periodically, where the shape and distribution influence the propagation of sound through the medium. Indeed, such materials have the characteristic of favoring a propagation orientation and blocking some frequencies in some directions (band gap).

This quality of the sonic crystal called band structure will be explained later, but it is one of the reasons why SC can be used for multiple applications, such as in the design of a wave breaker of the oceans, waves are propagated on the surface of the water and could be blocked by a forest of vertical bars placed periodically in the bottom of the sea.

Another application of these crystals is acoustic insulation, for example, they can be used to design anti-noise barriers for freeways by arranging for the prohibited band to encompass the frequencies emitted by the cars' motors, eliminating the sound.

That is why we will use sonic crystals as acoustic insulation for traffic noise in open spaces; this research thesis aims at optimizing and reducing the noise level caused by traffic noise through the sonic crystals using algorithms for that. Once we have explained the theoretical physical parts and introduced the subject, we will develop this thesis in several parts, first we will explain theoretical notions about the periodic means, to understand concretely what a sonic crystal is, how the waves propagate in these structures and the physical properties they possess. Then we will proceed to develop all the tests carried out showing graphs and the relevant results with explanations and comments about it, once we have previously studied our crystal, we will move to use evolutionary algorithms to find our perfect structure to avoid traffic noise and use our crystal as an insulator for noise.

4.1 PERIODIC MEDIUM

A periodic distribution of base elements (called "scatterers" when dealing with solid elements in the case of propagation of acoustic waves) is called "periodic medium". A set of these elements forms a crystalline structure, composed of cells or crystalline cells. Each property observed in one of them can also be observed in any other cell in the structure. There is only a single one-dimensional structure (1D), five two-dimensional (2D) and fourteen different three-dimensional (3D) (SINGAPORE, 2012).

Mathematically, the concept of periodic systems is an abstraction because it implies the existence of infinite structures and means. However, a finite crystalline structure may be considered as a periodic medium when taking into account contour conditions. The following figure shows some examples of real systems considered as periodic. The periodic system 1D has a periodicity according to a single direction, the 2D according to two directions and the 3D according to three.

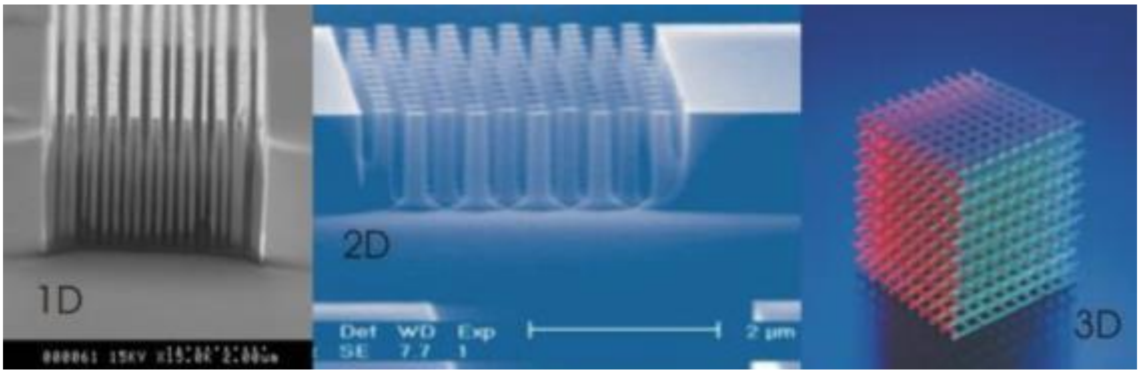


Illustration 25- a single one-dimensional structure (1D), five two-dimensional (2D) and fourteen different three-dimensional (3D).

4.2 RELEVANT CHARACTERISTICS AND PARAMETERS

We will proceed to explain the characterization of a crystal cell and the most relevant parameters that have to be taken into account.

A cell is a finite space containing a shape repeating itself by translation (or sometimes by rotation) in one or more directions, forming the entire crystal structure.

Mathematically, a cell is defined by a family of vectors considering that $\overrightarrow{a_i}$ are the vectors defining the lattice $\vec{R}$ in $\mathbb{R}^n$ with i = 1, . . . , n, thus $\vec{R}$ could be defined as:.

$$\vec{R}=\left\{\sum_{i=1}^{n} v_i \vec{a}_i\right\}$$ [6]

Where v_i are integer coefficients.

[6] Cell defined Mathematically

A concept of interest within the crystals is the unit cell. A small unit of crystal when repeated reproduces the entire crystal. If the unit cell consists of the lowest possible volume, it is called the primitive cell. It can be said that a unit cell is like a master template for the entire crystal and is the "base" for the construction of it.

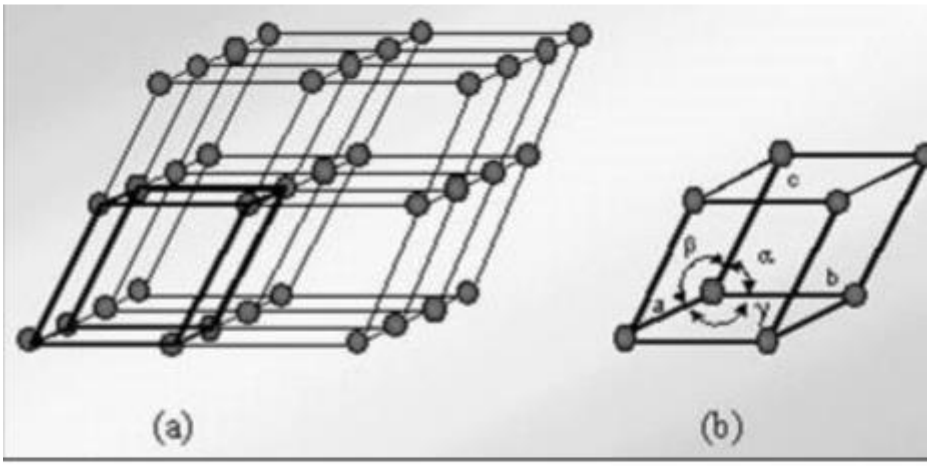


Illustration 26- The parallelepiped defined by the vectors forms a cell of the structure, also called primitive cell.

The parallelepiped defined by the vectors forms a cell of the structure, also called primitive cell. The combination of these cells constitutes the structure of the periodic medium. If the duplication of the primitive cells is made in the direct space, R is then called the direct structure (VALENCIA, 2011; Standardization; SINGAPORE, 2012).

A structure composed of atoms or molecules that is repeated again and again at regularly spaced intervals and with the same orientation, fits perfectly to the definition of crystal, being an important feature in this the periodicity or regularity of the arrangement in the models.

The net intermolecular attraction forces are maximal by the distribution of the atoms in the crystalline solid. These forces that maintain crystal stability may be ionic, covalent, van der Waals, hydrogen bonding or a combination of all of the above mentioned.

A periodic system is characterized by having a crystalline structure, that is, a periodic distribution of a material in a medium with different physical properties to those of this material. This system consists in the repetition of an elementary unit in a periodic network of points. These elementary units that form the whole of the structure are called "bases" and the periodic network of points is called the Bravais network.

The Bravais network can be defined as an infinite array of discrete points that have an invariable structure and orientation independently of the point of orientation. In this way, the entirety of a crystalline structure can be defined by a Bravais network and a base (Valencia, 2012).

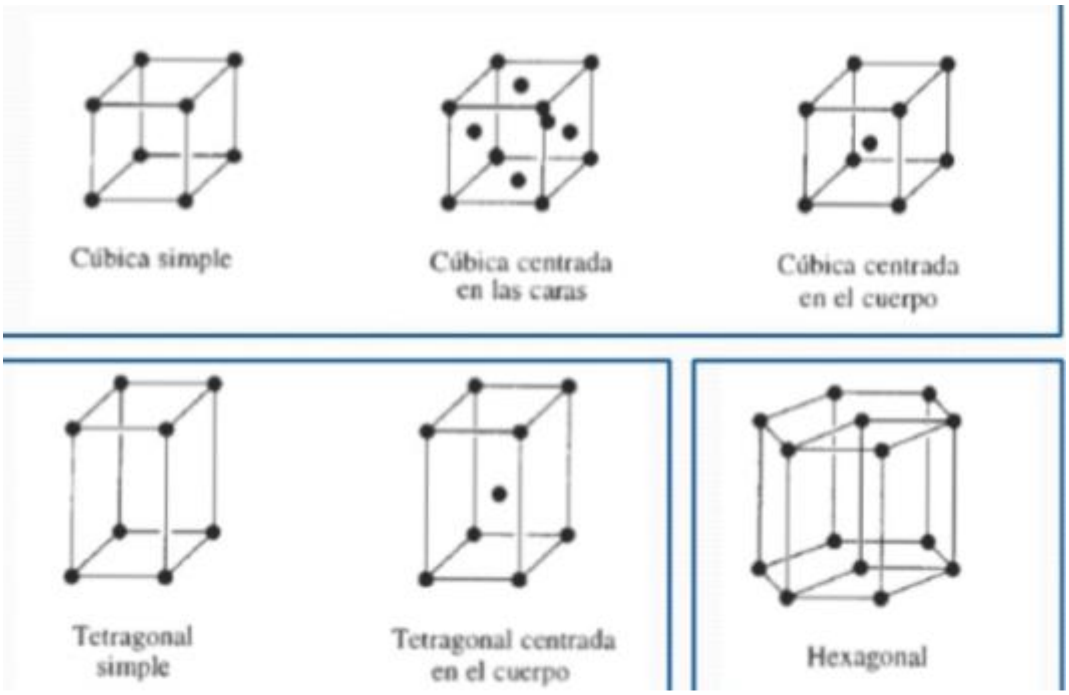


Illustration 27- Crystalline structure by Bravais network

Once we know the definition of a crystal structure, we will proceed to explain the parameters that are more important and that define each crystal lattice:

All these cells are considered primitive cells since they are able to cover the entire space through translations without leaving any gaps or overlaps. Their differences or characteristics are as follows:

Compact packing: This is when the atoms in the cell are in contact with each other. It will not always be so and in many cases will mediate a minimum distance between the electronic clouds of the different atoms.

Lattice Constance: This is the length of the sides of the unit cell. There can be only one, two or even three different network parameters depending on the type of network of Bravais we deal with. In the most common structures is represented by the letter a and c if there are two.

In our case our network parameter will be "a" fixed variable defined in our program in Matlab, in which its value is:

a=1,2 / 7 (m). [7]

Nodes or atoms per cell: As the name says is the number of nodes or atoms that each cell has. A square cell, for example, will have one node per cell since each corner shares it with four more cells.

Coordination number: It is the number of points of the network nearest, the first neighbors, of a node of the network. If it is a compact packaging structure, the coordination number will be the number of atoms in contact with another.

[7] Lattice constance

4.3 WAVE PROPAGATION AND PHYSICAL PROPERTIES

When a set of waves propagates through a medium containing many elements and each wave will be triggered by each of these elements and the scattered waves will be scattered by other elements, this is repeated by establishing a pattern (Romero).

If, furthermore, the scattered elements are placed periodically as they occur in the crystalline structures, the multiple dispersion leads us to a phenomenon known as band structures, denoted by this scattering, we can speak of:

1. Some waves propagate in a certain frequency of frequencies following the rules of scattering; this is called band allowed
2. However, there are other frequencies where the propagation is eliminated. This is called Band gap.

We proceed to explain in detail what Band gap exactly is, since in our case it is one of the physical phenomena that the sonic crystals have, and that we are interested in to elaborate our thesis, this physical phenomenon that the sonic crystals have and it is relevant today for different uses.

4.3.1 BAND GAP

In the study of solid-state physics, and particularly within semiconductor theory, the phenomenon of band structure is well known, where electronic levels are grouped into continuous bands separated by band gaps. This phenomenon can be interpreted within the framework of quantum mechanics as a consequence of the ondulatory behavior of the electrons inside the crystal, considered as a periodic medium. By analogy with the case of semiconductors, one can expect the same phenomenon to occur for other types of waves (mechanical, acoustic, electromagnetic). In recent years this has been demonstrated with the construction of photonic band gap crystals in which certain frequencies of light cannot be propagated. The study of these crystals also aroused interest in their acoustic and elastic equivalents (Physics, 2007).

The interest in making a band gap system lies in the possibility of using it to manipulate the properties of the corresponding radiation field, in the same way that electronic semiconductors are used. For the acoustic case, the possible applications are the construction of sound filters of high performance, isolation of noise or vibrations, as well as the study of fundamental physical questions such as the experimental study of the formation of the structure of bands or the effect of defects in the periodicity of the system.

If we want to explain how the Band gap is produced, we have to talk about Bragg's law.

Bragg's law is an explanation of the diffracted beams of a crystal. It is based on specular reflection. If it is considered that crystals can behave as diffraction gratings and a simplification is made that incident waves are specularly reflected on parallel planes of the crystal, the diffracted beam will only be visible when there is constructive interference between the reflecting rays successively in the different parallel crystalline planes. The constructive interference condition indicates that the difference between paths reflected by reflected rays in adjacent planes must be an integer multiple of n beam wavelengths. In this process diffusion is considered to be elastic, therefore, Lightning energy does not change in reflection.

4.3.1.1 Parameters of the Band Gap

The parameters that control the appearance of prohibited bands are:

- The type of symmetry of the structure.
- The contrast of speed between the wave propagating through the “host” material and through the dispersal element.
- The filled Factor, defined as the ratio between the volume occupied by each scatered and the total volume of the composition
- Topologie:

  The phenomenon of multiple scattering can be obtained through the use of two materials, each one with different propagation speeds. The component of low speed is called “host”.

We can distinguish two types of topology, according to the form of the dispersal element:

- Cermet Topology: The dispersal material consists in isolated inclusions, each one of which is completely surrounded by the "host" material.

- Network Topology: The dispersal material is connected and forms a continuous "network" over the whole structure.

Theorical studies (Economio and Sigalas, 1993), showed that for acoustic waves, the Cermet Topology is generally more favorable for the development of gaps. Otherwise, the electromagnetic waves, for which the Network Topology is more favorable.

Bragg's Reflection is a typical phenomenon of the wave propagation in a crystal. Likewise, Bragg's Reflection is the cause of the appearing of the so-called prohibited bands of energy. The first band of energy is associated to the first Bragg's Reflection, which corresponds to the following expression:

$$n\lambda = 2d \sin\theta$$ [8]

That for a normal incidence y n=1, we have that:

$$\lambda = 2d = \frac{c}{f} \rightarrow f = \frac{c}{2d} = \frac{c}{2a} \rightarrow k = \frac{\pi}{a}$$

Which corresponds to the limit of Brillouni zone. This expression is equivalent to the one of the condition of diffraction:

$$(k')^2 = (k + G)^2$$ [9]

[8] First reflexion of Bragg equation

[9] Diffraction condition

Which can be simplified:

$$k = \pm\frac{1}{2}G$$ [10]

Therefore, we have that:

$$k = \pm\frac{1}{2}G = \pm n\frac{\pi}{a}$$

So, the first Bragg's reflection occurs in $k = \pm\frac{\pi}{a}$, that is, for which vector that coincides with the vector which stays within the limit of the first Brillouin zone, and, therefore, achieves the conditions of reflection.

The Bragg reflection is a phenomenon characteristic of the propagation of a wave in a crystal. This reflection is the cause of the appearance of the so-called "band gap" (bands prohibited of energy).

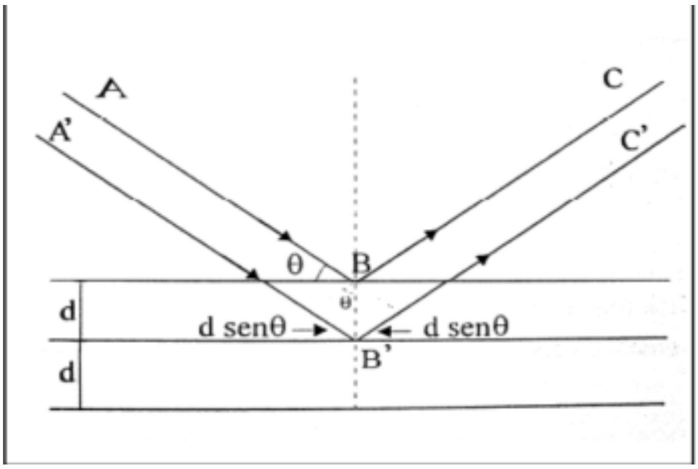


Illustration 28- Band Gap

Ranges of frequencies where sound propagation thought the periodic systems in not allowed. The BG are necessary for some important app of these structures such as filters of trapping or guiding waves. On the other hand, as well we will see later, the generation of the point defects in SC breaks the symmetry of the lattice and produces localized states, defines as modes that are localized around the point defects and

[10] Simplified equation

presenting an evanescent behavior inside the system these properties open the door for app as high precision filters or wave design.

4.4 ADVANTAGES COMPARED TO CONVENTIONAL ACOUSTIC SCREENS

Outdoor noise barriers are used to reduce noise disturbance from fixed industrial plant, from aircraft ground operations and from roads. Recent years have seen a growing interest in the potential for the use of sonic crystals as noise barriers. Sonic crystals take their name from the analogous effects of photonic crystals on light.

They consist of periodic arrays of circular cylinders and are known to give high attenuation at selective frequencies as a consequence of multiple scattering. The frequencies of highest attenuation can be found by assuming that an integer number of half wavelengths fits the distance between the scatterers. Additional attenuation bands may be achieved if the array is composed of resonant elements instead of solid cylinders. Possibly the main advantage of sonic crystals (SCs) is that, by varying the distance between the cylinders and the design of the resonant elements, it is possible to attain peaks of attenuation in a certain range of frequencies. Another advantage of an SC barrier would be its relative optical transparency. A further one would be its relative permeability to the wind, thus reducing the effects of barrier induced turbulence and wind-gradient enhancement. In principle, if SC barriers are used as highway noise barriers on both sides of a road, there should be less reverberation than between solid barriers. The appearance of an SC barrier might also have a rather positive aesthetic impact. After all, the interest in using SCs as barriers started with the discovery that a 'sculpture' consisting of vertical parallel cylinders acted as a sound barrier. Various possible designs of SC barriers have been considered. In addition to 'conventional' vertical circular cylinder arrays, the acoustical performance of horizontal cylinders' arrays above a reflecting plane, as well as arrays of elastic shells and composite resonant elements, was investigated both analytically/numerically and through laboratory measurements. The optimization of the design of SC arrays making use of acoustic lens effects and resonances was investigated. The outdoor performance of vertical cylinder arrays of resonant elements in configurations suitable for road traffic noise will be tested and compared with that of a simple barrier in various wind conditions.

After explaining all the theoretical part necessary to understand the conceptual part of what is going to be our work, we will begin to develop the idea; for this we must take into account the process that we are going to carry out, for that we use a program called Matlab, well known in the world of engineering, since it allows you to make very complex calculations and simulate results. So, our first objective will be to study our sonic crystals (SC), to know their capacity and observe their operation. For it, as we have said, we will use Matlab, in our case we will use a function that we have called "Calcluoyprocesado.m" appendix[1] ,we will attach it at the end of the work, so that you can observe the commands used; in this first part of the code we will define our crystal properties, as it is your network parametron, crystal dimensions, then use a function created Called "Example.m" [2], in which we will modify the dimensions of our SC to observe and study its operation, a variable that is the key for our study is going to be Insertion Loss (IL).

As we well know IL is: the reduction of noise level at a given location due to placement of a noise control device in the sound path between the sound source and that location. Usually rated in octave bands or 1/3-octave bands.

That is why in our work we will look at the result obtained from this variable as it will indicate when the sound pressure level we are able to avoid with SC.

Stages and objectives:

1. Our first objective will always be to keep in mind our IL, which is our sound pressure reduction, therefore our first objective will be to show a comparative graph where we have different global ILs to compare their result.

2. We will make different changes in the radios of our SC, to try to draw some conclusions with the results, that is why we will perform a lot of tests to study how our crystals work after changing the radios of these.

3. Once all the previous steps have been completed and we have made a conclusion regarding the operation of our crystals, and in which frequency ranges our crystals could be useful, we will use a function called evMOGA.

4. With our evMOGA function, which functions as an evolutionary algorithm, we will analyze the most useful generations and the ones useful to avoid traffic noise.

First of all, to begin with our first stage, and to realize our first objective, we must take into account a series of parameters that we have incorporated in our code, that should not be modified; we will show some parts of the code where these variables are found and we will explain why:

```
%% Geometty of the crystal
a=1.20/7; %paso de red
[X,Y]=meshgrid(0:3,1:7);X=X(:).';Y=Y(:).';
centrosx=a*(X-3.5);centrosy=a*(Y-0.5);
radio=(genes*a)*.95/2; %OJOOOO
%fin definición geometría

%repetición del cristal dos arriba y dos abajo
centrosx=[centrosx centrosx centrosx centrosx centrosx];
centrosy=[-1.2*2+centrosy -1.2+centrosy centrosy 1.2+centrosy 1.2*2+centrosy];
radio=[radio radio radio radio radio];

%%
```

Illustration 29- Matlab-code Geometry of the crystal

As we can see in this part of the code we design the geometry of our crystal, in which we can see a parameter called **a**, this is the network parameter of a crystal (lattice constants); this parameter cannot be modified, since it defines the basic geometry of the typical width under construction, this is why we will only modify the radios of our SC.

To give us an idea of the distances between our crystals and the value of the network parameter, we will show some images in which we can observe the dimensions:

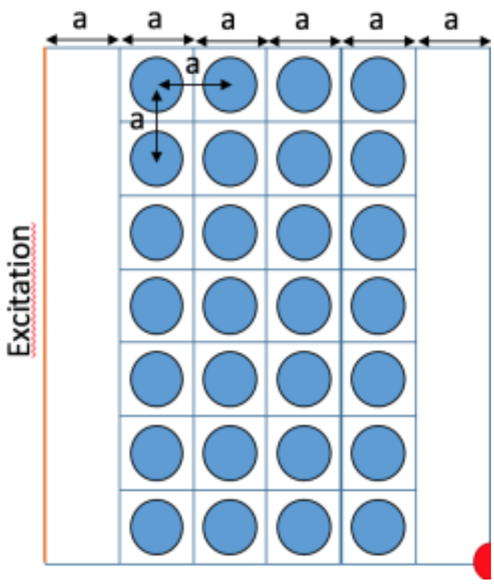


Illustration 30- Structure of our SC

Where in our case the network parametron, which is the separation between the crystals from their centers, is a = 1,2 / 7 (m). Approximately = 0.1714 m.

The incidence of the wave in MS is normal incidence, that is to say plane wave, since we know how the wave will influence, and knowing the structure of our crystals, as we know there are 4 columns with 7 rows; thus we have a total of 28 crystals of sound (SC).

Therefore, we will start to perform the first simulation, as we said we will make a first simulation modifying our variable genes, which is a variable that modifies the radius of our cylinders; in this way we will obtain a graph, where we will show the result of the said simulation overlapping the said results:

```
tic;
[ILbandafina,f,ILtercios,ILglobal]=calculosyprocesado(ones(1,28));
toc

%creación vector frecuencias para pintar bandas
fcent=100*2.^((0:17)/3)';
ff=[fcent*2^(-1/6) fcent*2^(-1/6) fcent*2^(+1/6)  fcent*2^(+1/6)]';ff=ff(:);
%creación vector IL para pintar bandas
ILterciosbandas=[zeros(18,1) ILtercios'  ILtercios' zeros(18,1)]';ILterciosbandas=ILterciosbandas(:);

%representación resultados
semilogx(f,ILbandafina,'o-b',ff,ILterciosbandas,'-k',f,f*0+ILglobal,'r','LineWidth',3)
```

Illustration 31- Matlab-code

In this first interaction we have the 28 crystals with the radius established in the beginning, and we obtained as a result:

- This would be the distribution of our crystals:

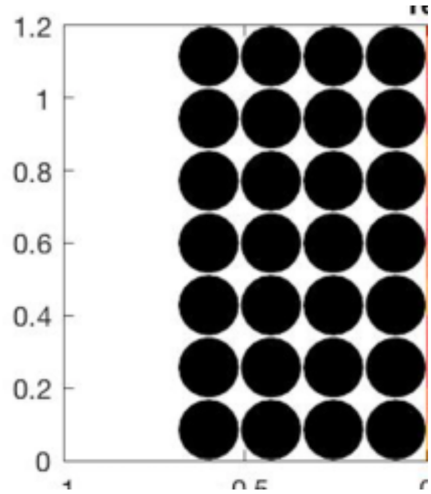


Illustration 32- First simulation radious of our SC with maximum values

In this graph we can observe our 28 crystals, all with genes=1. We have to know that our SC can have a radius from 0 to 1, in this case with the maximum dimension.

- And for the final solution on the IL, we obtained:

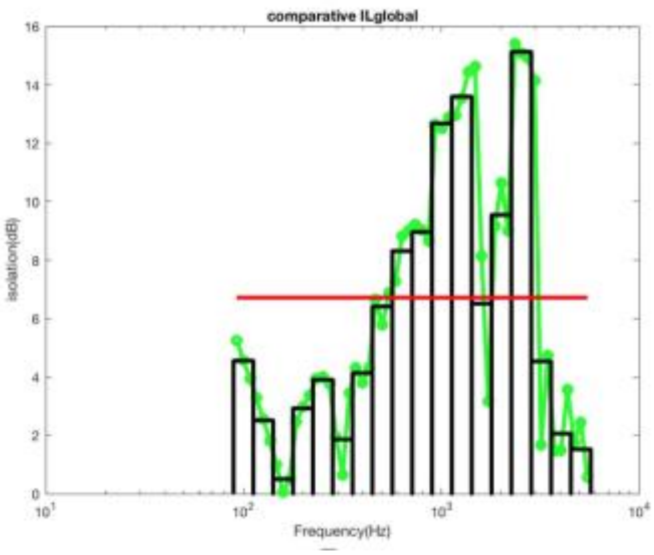


Illustration 33- Plot of the isolation in each band of frequency with all the radious with maximum values.

We can observe that we have our graph divided into thirds of octaves, and the IL for each frequency, as final result we obtain an IL average:

- IL=6.71 dB. [11]

Once these results have been obtained, we decided to perform more tests modifying the radios of our crystals so as to give us an idea of the possible results that we could obtain and to study our main parametron and most important Insertion Loss.

- In this case, we firstly add different values assigned to our SC, in order to observe and study the IL, and then we will add the results of IL

6.1 RADIOUS OF SONIC CRYSTALS

We are going to show some results that we obtained changing the radius of our SC.

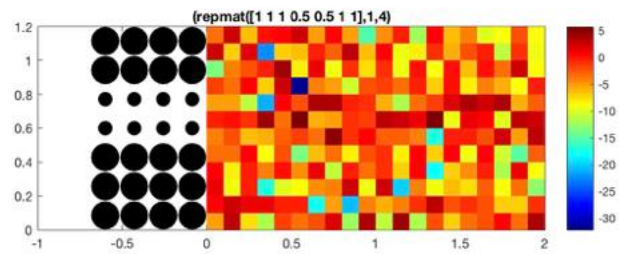


Illustration 34- Dimensions of our SC with the values of the radius("genes") equal to ([1 1 0.5 0.5 1 1],1,4)

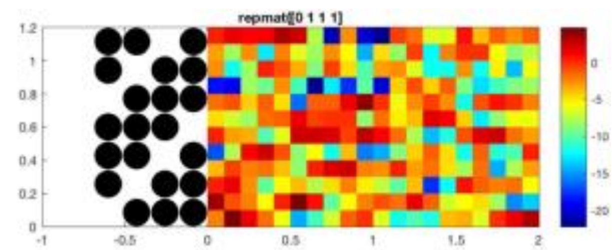


Illustration 35- Dimensions of our SC with the values of the radius("genes") equal to ([0 1 1 1],1,7)

[11] Insertion Loss

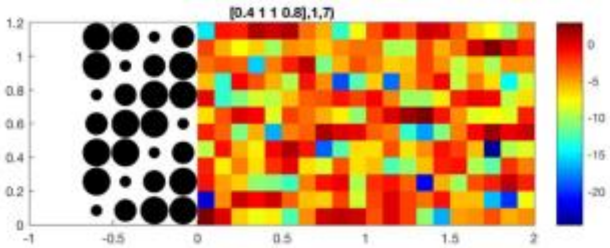


Illustration 36- Dimensions of our SC with the values of the radius("genes") equal to ([0.4 1 1 0.8],1,7)

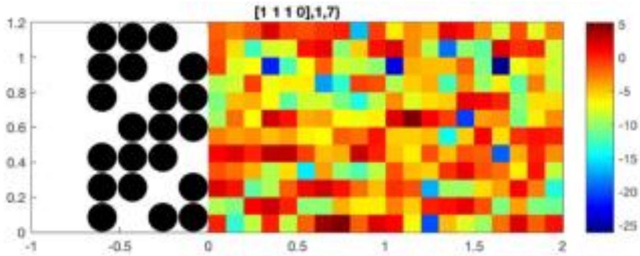


Illustration 37- Dimensions of our SC with the values of the radius("genes") equal to ([1 1 1 0],1,7)

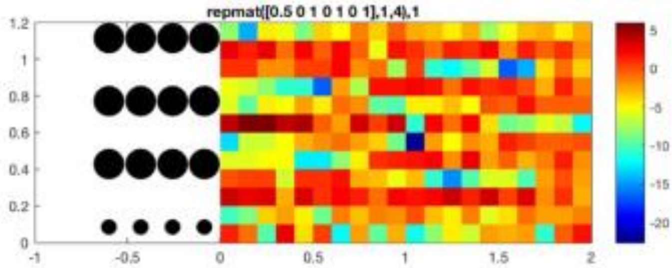


Illustration 39- Dimensions of our SC with the values of the radius("genes") equal to ([0.5 0 1 0 1 0 1],1,4)

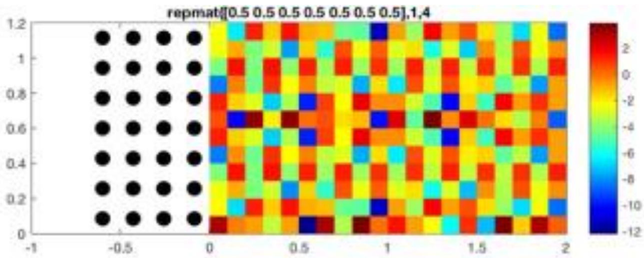


Illustration 38- Dimensions of our SC with the values of the radius("genes") equal to (0.5,1,28)

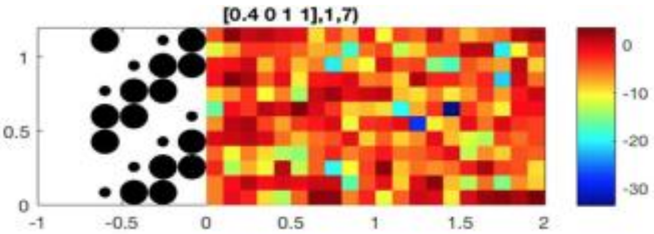


Illustration 40- Dimensions of our SC with the values of the radius("genes") equal to ([0.4 0 1 1],1,7)

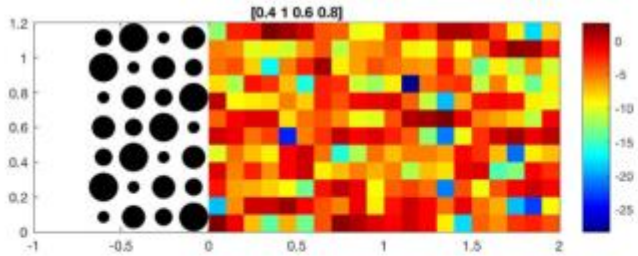


Illustration 41- Dimensions of our SC with the values of the radius("genes") equal to ([0.4 1 0.6 0.8],1,7)

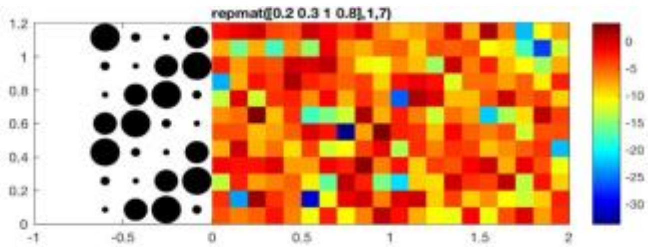


Illustration 42- Dimensions of our SC with the values of the radius("genes") equal to ([0.2 0.3 1 0.8],1,7)

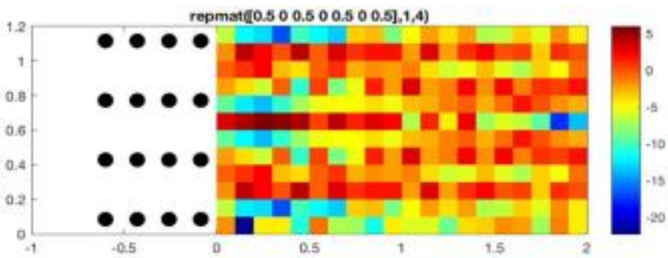


Illustration 43- Dimensions of our SC with the values of the radius("genes") equal to ([0.5 0],1,14)

6.2 IL GLOBAL SONIC CRYSTALS

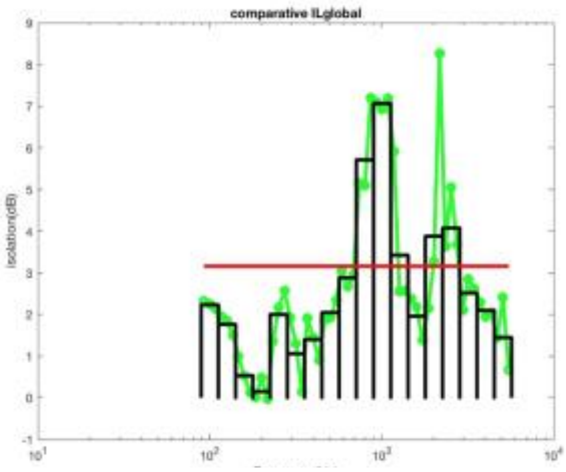


Illustration 44- Result of IL in each frequencies bands with genes equal to repmat([1 1 1 0.5 0.5 1 1],1,4)

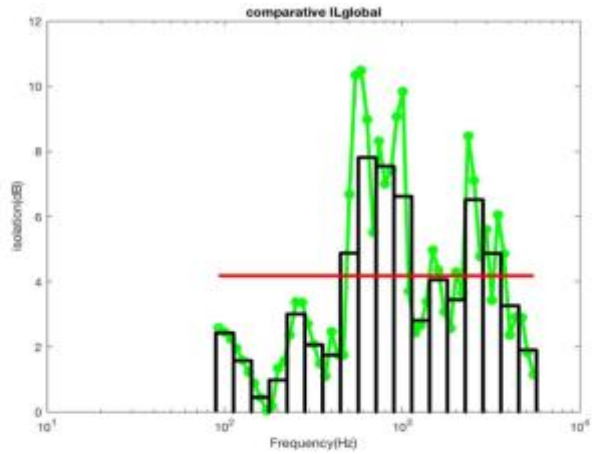


Illustration 45- Result of IL in each frequencies bands with genes equal to repmat([0 1 1 1],1,7)

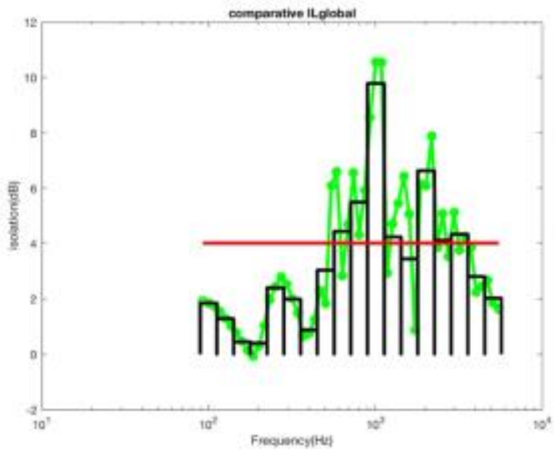


Illustration 46- Result of IL in each frequencies bands with genes equal to repmat([0.4 1 1 0.8],1,7)

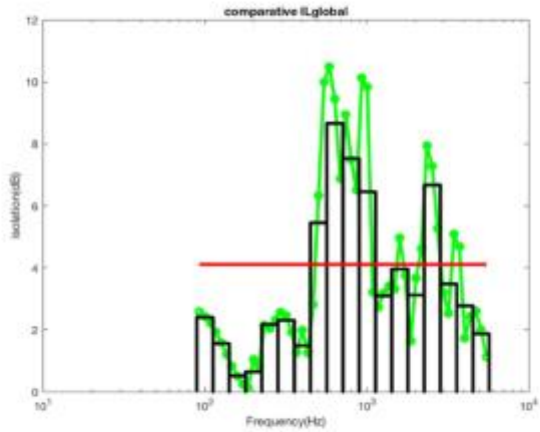


Illustration 47- Result of IL in each frequencies bands with genes equal to repmat([

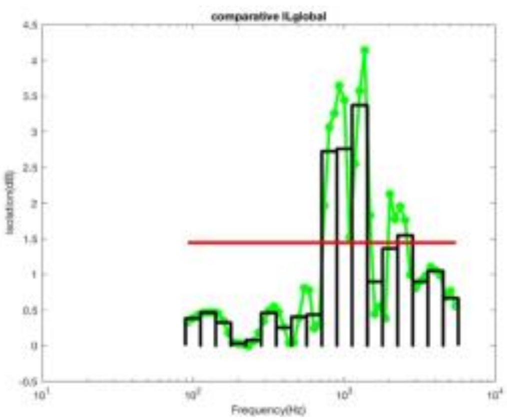


Illustration 48- Result of IL in each frequencies bands with genes equal to repmat([0.5 0 1 0 1 0 1],1,4)

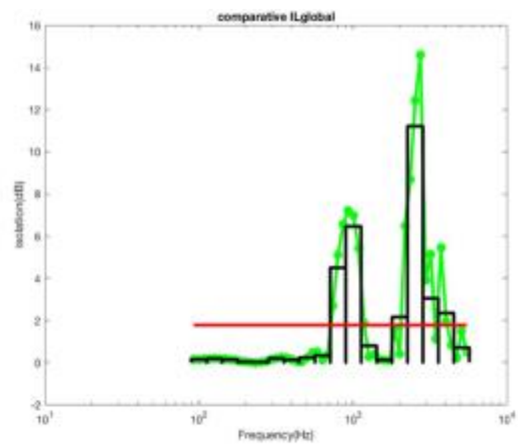


Illustration 49- Result of IL in each frequencies bands with genes equal to repmat(0.5,1,28)

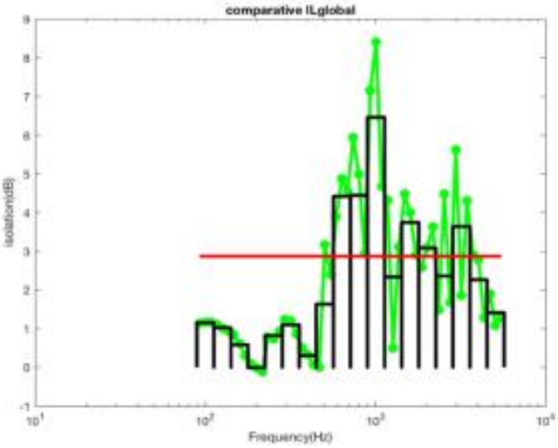


Illustration 50- Result of IL in each frequencies bands with genes equal to repmat([0.4 0 1 1],1,7)

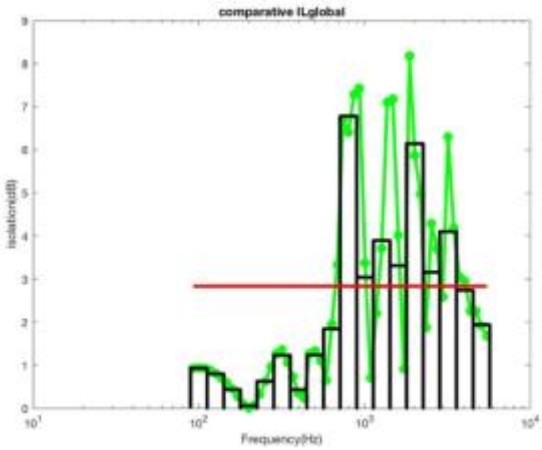


Illustration 51- Result of IL in each frequencies bands with genes equal to repmat([0.4 1 0.6 0.8],1,7)

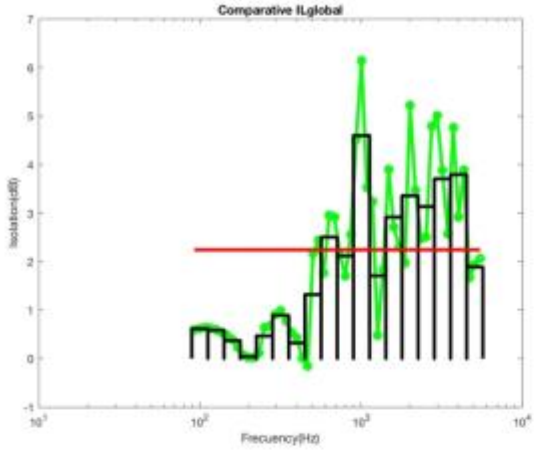


Illustration 52- Result of IL in each frequencies bands with genes equal to repmat([0.2 0.3 1 0.8],1,7)

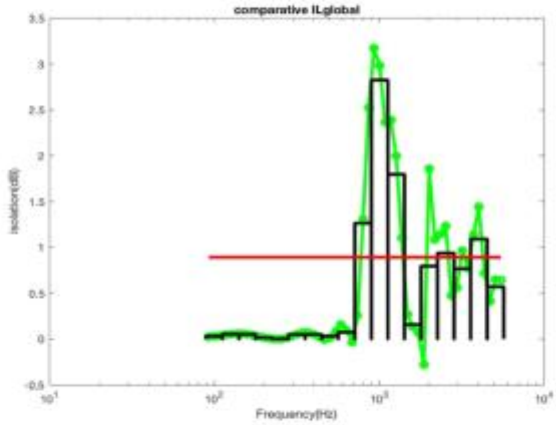


Illustration 53- Result of IL in each frequencies bands with genes equal to repmat([0.5 0],1,14)

These are the graphs we obtained through Matlab, and where we represented on the Y axis IL, where we can observe the dB, and the X axis we have the frequency bands; in this way we can know when we will reduce dB in each band. If we observe the graph, we can see a red bar which indicates the global IL global of all the frequency bands.

After realizing all the experiments, we realized that in reality, even repeatedly modifying the radios of our SC, we did not obtain a value of our insertion loss that fuses relatively good to be able to use the SC as an insulator and to reduce the sound pressure, like we can see in the following table:

Value of the variable "genes"	**Insertion Loss(dB)**
4 Repetitions of: ([1 1 1 0.5 0.5 1 1],1,4)	3.1572 dB
7 Repetitions of: ([0.4 0 1 1],1,7)	2.8715 dB
7 Repetitions of: ([0.4 1 0.6 0.8],1,7)	2.8332 dB
7 Repetitions of: ([0.4 1 1 0.8],1,7)	4.0114 dB
7 Repetitions of: ([1 1 1 0],1,7)	4.1096 dB
7 Repetitions of: ([0 1 1 1],1,7)	4.1778 dB
7 Repetitions of: ([0.2 0.3 1 0.8],1,7)	2.2423 dB
14 Repetitions of: ([0.5 0],1,14)	0.8916 dB
4 Repetitions of: ([0.5 0 1 0 1 0 1],1,4)	1.4435 dB
28 Repetitions of: (0.5,1,28)	1.7716 dB

Table 1- Values of the variable "genes"

It is why we say instead of looking at the global IL of each frequency we look at the octave band separately, and we could see that it is true that often global IL was not excessively good studying it globally, but instead if we fixed in a certain octave bands we could observe that if there is a considerable dB reduction therefore, it might make sense to use the SCs.

For that reason, our next step was to make an excel table where we would show all the results obtained with the different changes in the radios of SC, and seeing how it affected the IL to each octave band, now we will show a part of our graph, and we will attach in annex the whole table:

Frequency(Hz)	Atenuación(dB) repmat[1 1	repmat[1 1 1 0],1,7	repmat[0.4 0 1 1],1,7)	repmat[0.4 1 0.6 0.8	repmat[0.4 1 1 0.8]
92,59	2,5910	2,5881	1,1371	0,9255	1,9370
100,00	2,4452	2,4243	1,1618	0,9367	1,8597
108,01	2,2418	2,2134	1,1621	0,9295	1,7389
116,65	1,9523	1,9352	1,1154	0,8885	1,5510
125,99	1,5826	1,5831	1,0214	0,8063	1,2928
136,08	1,2232	1,1985	0,9343	0,7018	1,0178
146,97	0,8922	0,8390	0,8402	0,5927	0,7678
158,74	0,4488	0,5023	0,6137	0,4471	0,4610
171,45	0,0478	0,2387	0,3129	0,2666	0,1371
185,17	0,1589	0,1306	0,1008	0,0983	-0,0627
200,00	1,3316	1,0367	-0,0089	0,0001	0,2922
216,01	1,5688	0,8067	-0,1221	0,0664	1,0403
233,31	2,3612	2,1507	0,7934	0,3214	1,9834
251,98	3,3652	2,0456	0,7304	0,6183	2,4451
272,16	3,3601	2,3172	0,9345	0,9601	2,7896
293,95	2,7114	2,5650	1,2418	1,2627	2,5331
317,48	2,0722	2,4608	1,2091	1,3630	2,0155
342,90	1,4858	1,9191	0,8608	1,0617	1,4746
370,35	1,1000	1,2660	0,5146	0,7231	0,6442
400,00	2,4670	1,9946	0,3341	0,3547	0,7478
432,02	1,7667	1,2503	0,0660	0,2280	1,2617
466,61	1,7434	2,8164	-0,0049	1,2617	2,3037
503,97	6,6805	6,3363	3,1712	1,3383	1,8245
544,32	10,3460	10,0026	2,3929	1,0991	6,0887
587,89	10,4903	10,4879	3,8971	0,6567	6,5866
634,96	8,9786	9,4478	4,8779	1,9488	2,8365
685,80	5,5139	6,8748	4,5414	3,3313	4,6854
740,70	8,3078	8,9402	5,9383	6,6977	6,5577
800,00	7,0069	7,4842	4,9920	6,4073	4,3052
864,05	7,4163	6,4997	2,9458	7,2809	5,9284
933,22	9,0678	10,1297	7,1485	7,4282	8,5662
1007,94	9,8438	9,8306	8,4084	3,3753	10,5563
1088,63	3,7058	3,2081	4,6736	0,7067	10,5295
1175,79	2,4300	2,7255	4,3175	2,1962	2,9390
1269,92	2,6522	3,1726	0,4929	3,7053	4,7202
1371,59	3,3933	3,4101	3,1033	7,1061	5,4486
1481,40	4,9673	3,3169	4,4751	7,1752	6,4366
1600,00	4,3467	4,9650	4,0012	4,0106	5,0646

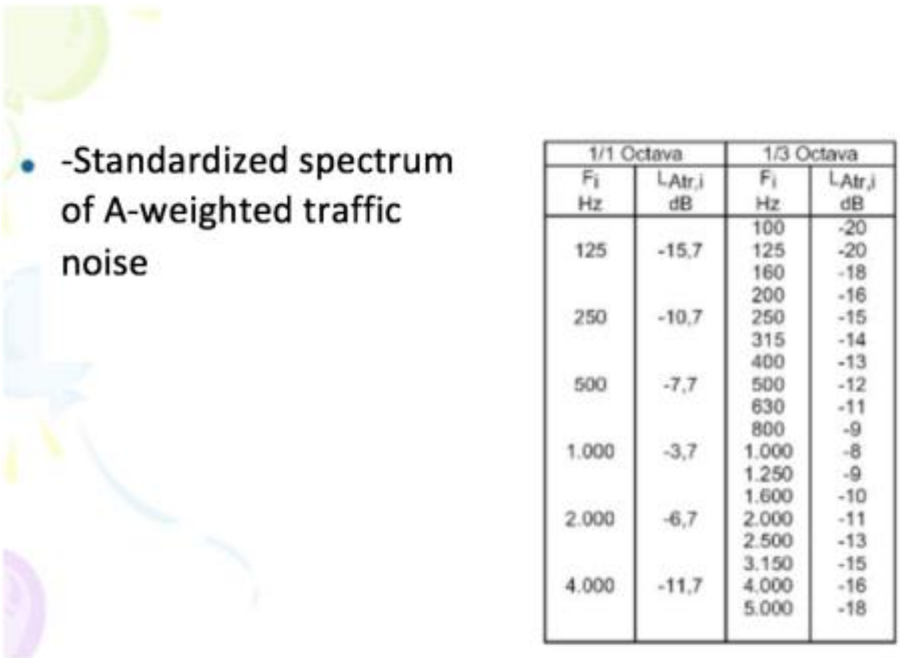
Table 2- IL for each frequencies

After realizing this table, we realized that with the characteristics that you possess our SC below 500 Hz we could not do anything since the IL was practically null in these ranges of frequencies inferiors to 500 Hz.

We will show a part of our table of excel, although the whole table will be attached in [3].

First of all, we should know exactly for our work that range of counts were important to know if we could continue with our work or not, for them as we know we are analyzing the possible isolation of our sonic crystals for traffic noise in open space, so it is important to know that:

The traffic noise spectrum with A-weighting has a maximum in 1000 Hz:



- -Standardized spectrum of A-weighted traffic noise

1/1 Octava		1/3 Octava	
Fi Hz	LAtr,i dB	Fi Hz	LAtr,i dB
		100	-20
125	-15,7	125	-20
		160	-18
		200	-16
250	-10,7	250	-15
		315	-14
		400	-13
500	-7,7	500	-12
		630	-11
		800	-9
1.000	-3,7	1.000	-8
		1.250	-9
		1.600	-10
2.000	-6,7	2.000	-11
		2.500	-13
		3.150	-15
4.000	-11,7	4.000	-16
		5.000	-18

Illustration 54- Standardized spectrum of A-weighted traffic noise

Therefore, we realized that in reality our sonic crystals had importance the octave band of 1kHz, we can observe it in the excel table of the [3]:

In fact, the next step was to use a program of evolutionary algorithms that we will explain next, but for this we must mark a frequency range which we are going to evaluate, this range will evaluate from 500Hz to 3.2 kHz, since that is where our crystals are influencing in the propagation of sound.

Therefore, for our Project we decide to choose the octave bands of 1kHz and 2Khz, we proceed to analyze with our evolutionary algorithm that we will explain next.

6.2 EvMOGA

Now, in this section of our project, as we have said before, once we have selected our frequency range, with which we want to work and with which we know our SC can act and perform attenuations, we will use this program that acts as an evolutionary algorithm.

An evolutionary algorithm consists in methods of optimization and search for solutions based on the postulates of biological evolution. It maintains a set of entities that represent the possible downsides which are mixed and compete with each other.

Therefore, this optimization program based on evolutionary algorithms allows you, once defined one or several cost functions (Parameters of some physical magnitude, in our case the Insertion Loss), to make a combination between one or several individuals with values as low as possible of those parameters.

This paper shows a promising method for acoustic barrier design using a new acoustic material called Sonic Crystals (SCs). The configuration of these SCs is a multiobjective optimization problem which is very difficult to solve with conventional optimization techniques. The paper presents a new parallel implementation of a Multiobjective Evolutionary Algorithm called ev-MOGA and its application in a complex design problem. Ev-MOGA algorithm has been designed to converge towards a reduced, but well distributed, representation of the Pareto Front (solution of the multiobjective optimization problem). The algorithm is presented in detail and its most important properties are discussed. To reduce the ev-MOGA computational cost when objective functions are substantial, the basic parallelization has been implemented on a distributed platform.

6.3 CHARACTERISTICS OF EVOLUTIONARY ALGORITHMS

The fundamental characteristic of evolutionary algorithms lies in the methods of generating solutions: starting from a set of initial solutions and using a set of search operators to refine the final solution. To accomplish such a refinement of the solutions, classical techniques such as Hill Climbing D may be used, supplemented with biological scanning mechanisms: population solutions, genetic operators.

6.4 DEVELOPMENT GENETIC ALGORITHM

Once explained what an evolutionary algorithm is, in order to understand the process we are going to carry out next, now we will explain the development of our project in this part of the work.

As we well said in the last part of our project, we had selected a frequency range to base on for our isolation. Therefore, we say to evaluate the octave band of 1 kHz and 2kHz.

The first part in order to carry out these calculations and obtain the IL we got with our sonic crystals, consisted in modifying our code in Matlab. During our first test it consisted in studying the performance in the octave band of 1kHz, and in modifying part of our code, with the purpose that our circuit went only through the frequencies that belonged to the octave, instead of studying all the frequencies range, as we had at the beginning.

We add part of that code, even though we will see the complete code in the [4].

```
for kk=19:36
% k=1:length(f)
    k= f(kk)*2*pi/340;
    pressure(:,:,kk)=MS(centrosx,centrosy,radio,x,y,k,3);
    if pintar
        figure(10);close ;figure(10) %truco asqueroso.
        angulos=0:pi/10:2*pi;
        pcolor(x,y,20*log10(abs(pressure(:,:,kk))));shading flat;colormap jet;
        title(num2str(round(f(kk))));colorbar;%set(gca,'CLim',[0 10])
        hold on
        for ii=1:length(centrosx);
            patch(centrosx(ii)+radio(ii)*cos(angulos),centrosy(ii)+radio(ii)*sin(angulos),'-k');
%              //Utilizamos este comando para asi poder recrear nuestra figura geometrica.
            hold on
        end
        axis equal; hold off;axis([-1 2 0 1.2]);drawnow
    end
end
```

Illustration 55- Matlab code

As we could previously see, the circuit passed from the position 1 to the longitude of, therefore we modify these values, in order to make it go through the frequency values in which we are interested in our project.

With this code we wanted to study the behavior of our crystals at the octave band of 1kHz, and especially to obtain the best combination to get the highest possible Insertion Loss. As we already said at the beginning, with our code we obtained the radius our crystals should have in order to get the highest possible Insertion Loss.

Now we are going to introduce some new functions that are important for our code; as we already said, in order to make this optimization, we use a series of functions called evMOGA, it is a pointer that carries out an optimization based on evolutionary algorithms.

```
%% Minimal algorithm parameters set (problem characteristics)
clear
close all
clc

eMOGA.objfun='calculadorfuncionesdecosto';% m-function name for objectives computation
eMOGA.objfun_dim=1;                % Objective space dimension
eMOGA.searchspaceUB=ones(1,28);    % Search space upper bound
eMOGA.searchspaceLB=zeros(1,28); % Search space lower bound
eMOGA.Nind_P= 1000;                 % Individuals for the P population Recomendaría 1000 como poco
eMOGA.Generations= 100;            % Number of generations
eMOGA.n_div= 200;                  % Number of division for each dimension
```

Illustration 56- Matlab code

In this image we can observe our function lanzaroptimizacion.m, that was responsible for launching our optimization, where we could choose the number of individuals which would have our launch and their respective generations; as we can observe, this function called the function ‘calculadorfuncionesdecosto’, said function:

```
function [J]=calculadorfuncionesdecosto(genes)
%funcion que calcula los parametos de costo a partir de los valores de los
%genes.

[ILbandafina,f,ILtercios,ILglobal2]=calculosyprocesado2(genes);
J=-ILglobal2; %se cambia el signo porque EVMOGA lo que hace es minimizar

return
```

Illustration 57- Matlab code

As you can see, we obtained a value of Insertion Loss, adjusted at some values of genes that will be changing according to the individuals and the generations, to obtain the higher result for the IL.

We made the said optimization for the octave band of 1kHz, and we obtained the following result:

RESULT
Nind_A=1
Objectives min values: -11.1845

Therefore, we could realize that we improved the isolation a lot, compared to the values obtained at the beginning, in this case just watching the octave band of 1Khz, now we have an isolation of 11.18dB.

In the Appendix[5] we will be able to observe the value from the first to the last generations, in order to realize how our IL has improved. We are interested in the value of IL, as we said, but especially we want to know which radius have had those SC to obtain that isolation. For this, with the values obtained with our function, we will generate a graph in order to show how our crystals should be for obtaining an isolation of 11.18dB:

- Now, we are going to attached the values of the radious of our SC should have to obtain this isolation:

0,97
1,00
1,00
1,00
1,00
1,00
0,98
0,98
0,98
1,00
0,96
0,98
1,00
0,99

1,00
1,00
1,00
1,00
0,99
1,00
1,00
0,99
1,00
0,95
0,95
0,96
1,00
1,00

Table 3- Values of the radious of SC

Now, we are going to show the plot of our sonic crystals if we use the values that we showed before at the table excel:

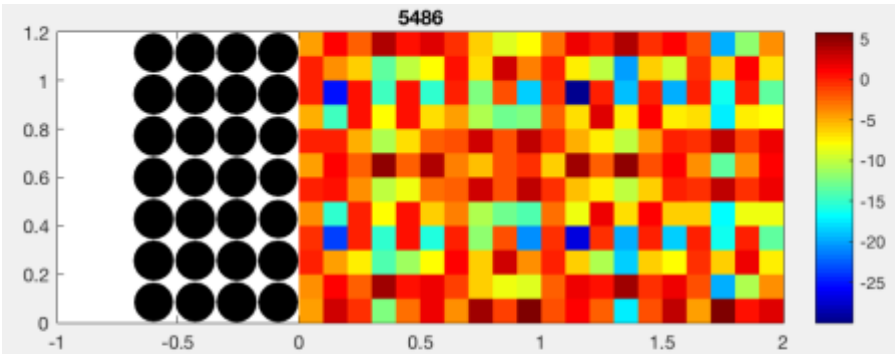


Illustration 58- Dimensions of our SC with the values of the radius("genes").

This plot shows the radious that our SC should have if we want to obtain a 11.18dB of isolation.

Now we will proceed to perform the same simulation with the octave band of 2khz, where we will show the radius dimensions of our criteria through a table of excel and later we will show the graph created in Matlab. We will use our code created in Matlab where we will evaluate our plane wave (MS) when interacting with the sonic crystals, to study their insulating behavior.

To do this, we first obtain the value of IL, which we will have in the octave band of 2 kHz:

RESULT
Nind_A=1
Objectives min values: -11.5115

This was the result that we obtained after performing the optimization of the octave band of 2Khz, mainly, we obtained:

IL= 11,51 dB

Now we will proceed to show an excel table where we show the radios that our crystals of sound should have to obtain this insulation in the band of 2Khz.

Excel sheet:

0,11	0,18
0,99	0,55
1,00	0,58
0,33	0,95
1,00	0,33
0,69	0,92
1,00	0,93
1,00	0,60
0,67	0,03
0,25	0,30
1,00	0,98
0,95	0,31
1,00	0,00
0,68	0,07

Table 4- Values of the radious of SC for 2Khz.

Therefore, these would be the values that should have as radius our crystals to obtain the insertion loss in the band of 2kHz octaves.

In order to better appreciate how our crystals would be with the radios previously mentioned, through Matlab we will make a plot so we can observe our Sonic crystal:

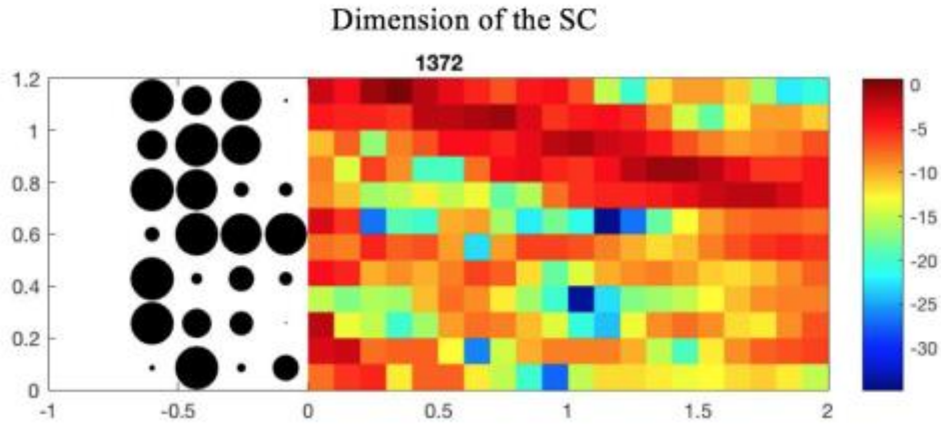


Illustration 59- Dimensions of our SC with the values of the radius("genes")

In this graph made with Matlab, we can see the 28 sonic crystals with their different radious, which we have shown in the excel table shown, in order to obtain an insertion loss in the 2 kHz octave band of 11.51 dB.

Once we obtained the results of the optimization of the two selected octave bands and observed the characteristics that our SC should have to obtain said values of IL and prove that we are having some better values of isolation for those bands, we decided for the next step to make an optimization based on genetics algorithms, but Multiobjective, that is, in this case we are evaluating the two octave bands together, in order to know which would be the optimization of isolation that we would obtain evaluating the two octave bands together.

Since they are two of the bands in which we are more interested for our optimization, we have to pay attention to the fact that we could think of putting a wall of concrete instead of putting the SC. In this way we would neither obtain more than 25 dB of isolation, since it is impossible, and with the case of the SC, we obtain more benefits, like the fact that they can let the air pass and other aspects.

Therefore, we are now going to explain the Multiobjective and what we are going to do next.

6.5 MULTIOBJETIVE

One can say that the true optimization is Multiobjetive: the real problems in general involve more than one objective at the same time.

Multi-objective optimization (also known as multi-objective programming, vector optimization, multicriteria optimization, multiattribute optimization or Pareto optimization) is an area of multiple criteria decision making, that is concerned with mathematical optimization problems involving more than one objective function to be optimized simultaneously. Multi-objective optimization has been applied in many fields of science, including engineering, economics and logistics where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives.

Now, after doing some basic tests on our sonic crystals, focusing only on the octave bands of 1kHz and 2kHz, before we had always obtained individual values for each octave, now we are going to make a multi-objective.

As we explained at the beginning, the multiobjective is useful to make the comparison between two or more variables. For that we had to make first some modifications of the code, such as:

```
function [J]=calculadorfuncionesdecosto2(genes)
%funcion que calcula los parametos de costo a partir de los valores de los
%genes.

[ILbandafina,f,ILtercios,ILglobal,ILglobal2]=calculosyprocesado(genes,0);

J(1,1)=-ILglobal; %IL a 1000 Hz;
J(1,2)=-ILglobal2;%IL a 2000 Hz;
return
```

Illustration 60- Matlab code

We have modified our code by adding one parameter more, in order to obtain the IL of the two bands. Obviously we modified the circuit to go through the two octave bands and other lines we were interested in for our results, they are added in the appendix to be eventually studied.

Now we are going to proceed to obtain a result of our Insertion Loss for every octave band, but keeping in mind that the crystals have the same characteristics.

After the obtained results, we realized that if we watch the path of the generations, it is true that there was not too much modification of the value of IL.

For that we decided to use a parameter that has the function evMOGA, which obliges to create an initial subpopulation at a determined value, so we choose to make this in order to see if we would obtain better values of optimization, and above all, an improvement at the end of the generations, but the results were as follows[6]:

######### generation 1#########
Nind_A=1
Objectives min values: -11.3524 -8.46254

RESULT
Nind_A=21
Objectives min values: -11.4211 -8.50294

In these results we can observe, the final value of insertion loss that we would obtain for the band of 1kHz and of 2Kh respectively, we would have:

- for the 1 kHz octave band:
  - 11.42 dB

- for the 2 kHz octave band:
  - 8.50 dB

Therefore, these values that we obtained would be the dB that we isolate with our crystals to those bands of octaves of frequency, now we will proceed to add a table with the values of the radious of our crystals that they should have to be able to come to create that insulation of traffic noise in open spaces.

Performing a Multiobjetive optimization and comparing the two octave bands, we obtain more than one option for the value of the radius of our SC, in this case we obtained 21 individuals, namely 21 combinations with which we will obtain different values of isolation. In the following graph we represented our 21 individuals:

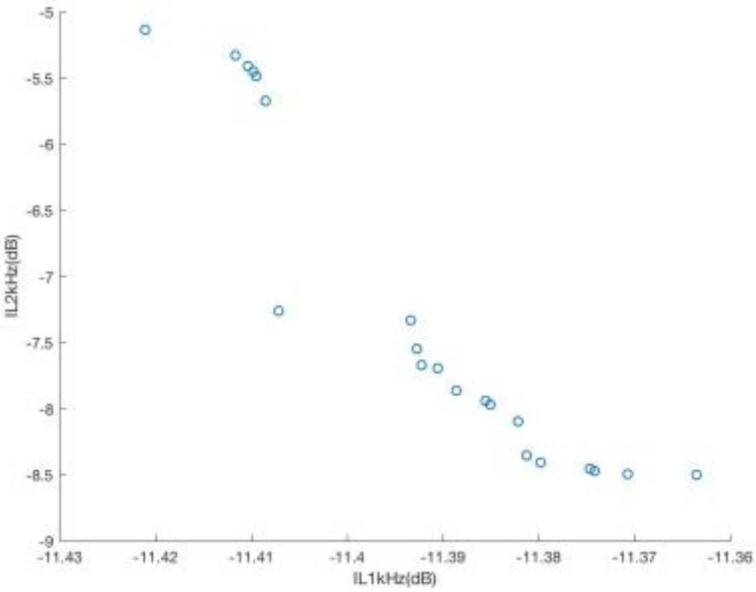


Illustration 61- Plot of the different individuals for 1kHz and 2kHz octave band

In this graph we can observe the 21 arranged individuals, where on the x axis we have represented the IL of our band of 1kHz and on the y axis we have represented our band of 2kHz.

As we can see in our case, our best individual is:

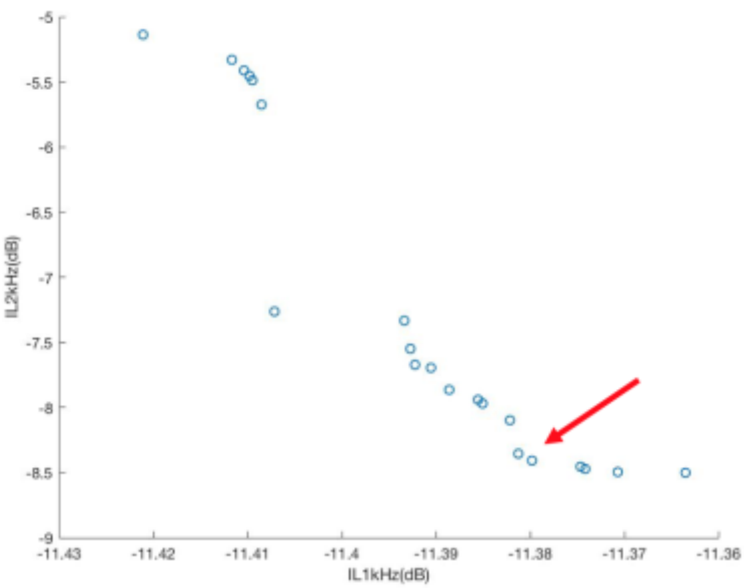


Illustration 62- Selection of the best individual

Using the values resulting from this individual as radius for the sonic crystals, we would obtain approximately 11.38 dB for the band of 1kHz and 8.5 dB for the band of 2kHz.

We will ad in the Appendix [7] an excel table, where we will show the different values that the radius of the SC could have for every individual.

In order to have a more perceivable visual representation, we are going to visualize through Matlab some of the values of different individuals, in order to observe how our sonic crystals would be:

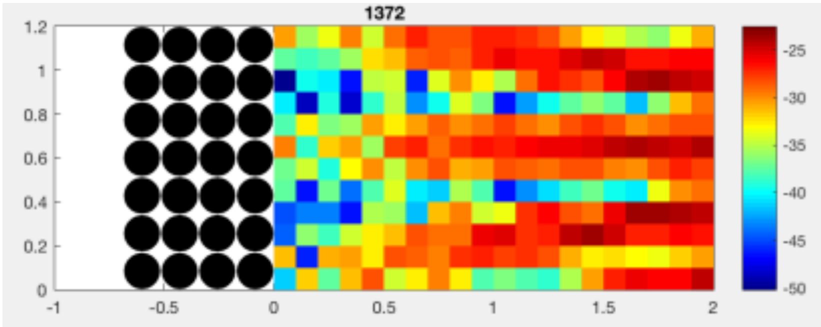


Illustration 63- Dimension of the radious of the SC for 1kHz and 2kHz octave band

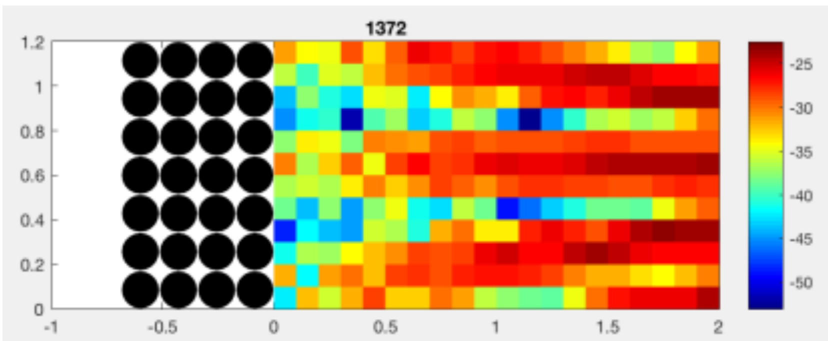


Illustration 64- Dimension of the radious of the SC for 1kHz and 2kHz octave band

It may seem that it is the same graph, but no! They are different but the radius dimensions of the SCs vary a bit because the difference is not appreciated, but in appendix [7], we will see the excel table with the values.

The purpose of our project was to use sonic crystals as acoustic screens, that is, being able to replace conventional acoustic screens with sonic crystals; after analyzing these two octave bands, we could observe that we obtained isolation, but not sufficiently, especially when we were operating with the two bands at the same time.

This is why we decided to go back to observe the values of our table, where we could see the insertion loss we obtained in each frequency, in order to verify whether we could select another frequency range which could always be effective, and considering which bands affected traffic noise.

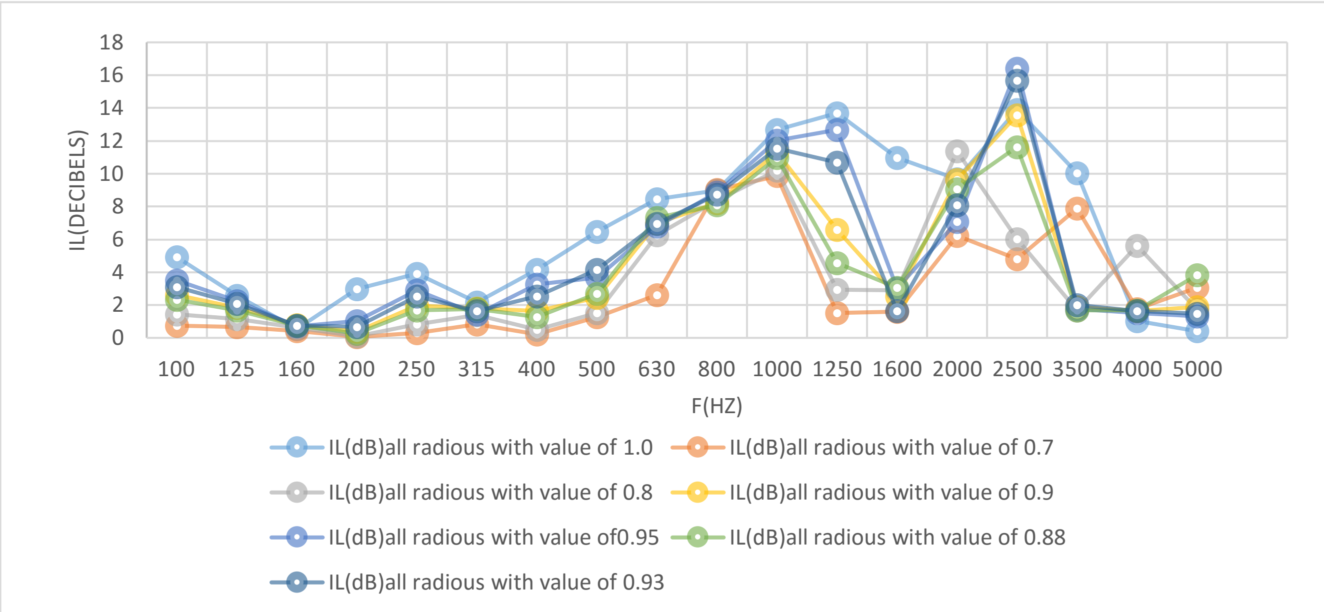


Table 5- Plot with the different values of IL in each frequencies for different radious value.

That is why we decided to proceed in the same way and analyze the band of 500Hz and 1kHz, in order to see the behavior of the wave when interacting with the SC and whether we could get a higher insertion loss with the band of 500 Hz.

Firstly, we are going to modify the corresponding parameters in our Matlab function, in order to study our new selection of octave bands of frequency.

After making our program in Matlab, we obtained our values of insertion loss that we would have with our sonic crystals for the mentioned octave bands of frequency.

######### generation 1#########
Nind_A=1
Objectives min values: -11.3524 -6.26657

RESULT
Nind_A=14
Objectives min values: -11.4161 -6.26657

These were the results we obtained with the bands of 1kHz and 500khz[8].

In these results we can observe, the final value of insertion loss that we would obtain for the band of 1kHz and of 500Hz respectively, we would have:

- for the 1 kHz octave band:
    - 11.41 dB

- for the 500 Hz octave band:
    - 6.26 dB

Performing a Multiobjective optimization and comparing the two octave bands, we obtain more than one option for the value of the radius of our SC. In this case we obtained 14 individuals, namely, we have 14 combinations with which we would obtain different values of isolation. In the following graph we represented our 14 individuals:

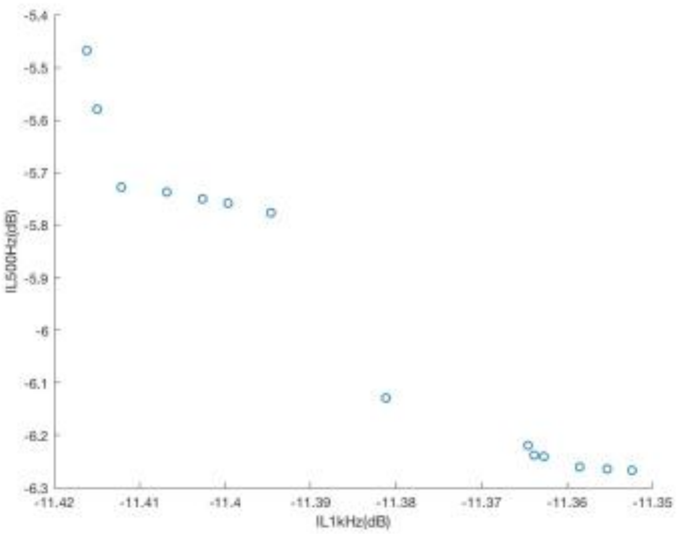


Illustration 65- Plot of the different individuals for 1kHz and 500Hz octave band

In this graph we can observe the 14 arranged individuals, where on the x axis we have represented the IL of our band of 1 kHz, and on the y axis we have represented our band of 500Hz.

As we can see, in our case our best individual is:

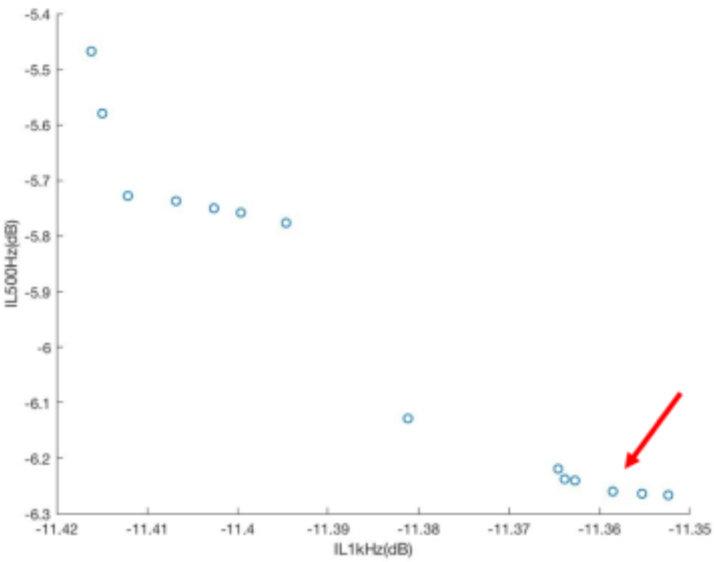


Illustration 66- Selection of the best individual

Using the values resulting from this individual as radius for the sonic crystals, we would obtain approximately 11.36 dB for the band of 1kHz and 6.25 dB for the band of 500Hz.

We will ad in the appendix [8] an excel table, where we will show the different values that the radius of the SC could have for every individual.

In order to have a more perceivable visual representation, we are going to visualize through Matlab some of the values of different individuals, in order to observe how our sonic crystals would be:

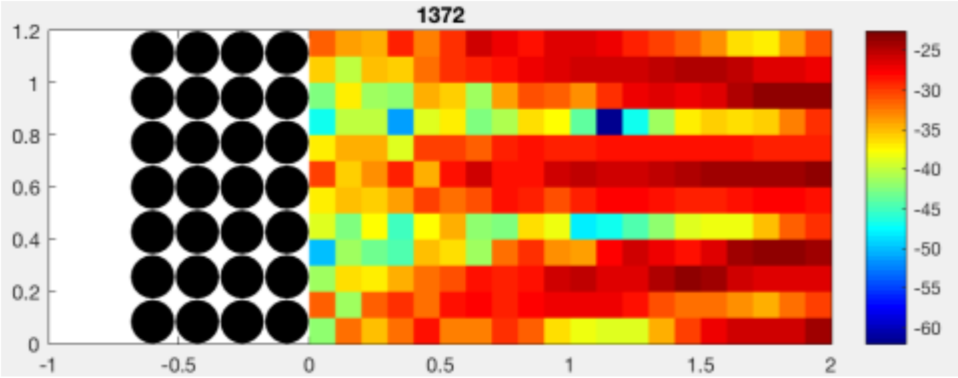


Illustration 67- Dimension of the radious of the SC for 1kHz and 500Hz octave band

Here we observe the values of the radious that our SC must have to obtain the insertion Loss, all the other values that our SC can obtain as a radius will be added in the appendix [9].

As we could observe from the result, after performing the optimization with the bands of 1kHz and of 500kHz, it was not sufficiently good, since the value of the Insertion Loss we obtained for the band of 500 Hz was quite low, and we can’t use it as an acoustic screens.

CONCLUSION

After making this project, in the last few months our main objective was to study the behavior of the sonic crystals when analyzing specific bands of frequency, but especially when performing multiobjective and comparing more than one band of frequency. As we said before, the SC were first studied through the sculpture made by Eusebio Sampere, where one could find a periodic structure formed by metallic cylinders. From that moment some experiments have been carried out, bringing awareness on the phenomenon of these SC when creating a band structure inside their structure, and on the fact that we could find phenomenons like Band gap in our crystals. This led us to consider whether we could improve the conventional acoustic screens with sonic crystals. That is why we made this project, with the purpose of analyzing some bands of frequency and studying the behavior of our sonic crystals.

We must know that the SC have several benefit characteristics if compared to the conventional acoustic screens. Possibly the main advantage of sonic crystals (SCs) is that, by varying the distance between the cylinders and the design of the resonant elements, it is possible to attain peaks of attenuation in a certain range of frequencies. Another advantage of an SC barrier would be its relative optical transparency. A further one would be its relative permeability to the wind, thus reducing the effects of barrier induced turbulence and wind-gradient enhancement. In principle, if SC barriers are used as highway noise barriers on both sides of a road, there should be less reverberation than between solid barriers. The appearance of an SC barrier might also have a rather positive aesthetic impact. After all, the interest in using SCs as barriers started with the discovery that a 'sculpture' consisting of vertical parallel cylinders acted as a sound barrier. Various possible designs of SC barriers have been considered. In addition to 'conventional' vertical circular cylinder arrays, the acoustical performance of horizontal cylinders’ arrays above a reflecting plane, as well as arrays of elastic shells and composite resonant elements, was investigated both analytically/numerically and through laboratory measurements. The optimization of the design of SC arrays making use of acoustic lens effects and resonances was investigated. The outdoor performance of vertical cylinder arrays of resonant elements in configurations suitable for road traffic noise will be tested and compared with that of a simple barrier in various wind conditions.

For all these reasons we believe that SC must be studied thoroughly, in order to work more with them and enhance all their characteristics. We must say that after making all the necessary test and studying firstly the bands of 1 kHz and 2kHz, and then the bands of 500Hz and 1kHz, we realized that the results were not sufficiently good, but this apparently showed that only with multiple scattering it is not possible to isolate more than one octave. However, if we watched the bands separately, we would reach an isolation of approximately 12 dB for some bands.

TABLE OF ILLUSTRATIONS

TABLE OF TABLES

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Appendix [1]

```
function
[ILbandafina,f,ILtercios,ILglobal]=calculosyprocesado(genes,pintar)
if nargin<2
    pintar=0;
end
% // If we don't have the value of pintar,we force it to be 0.

if (size(genes,1)==1)&&(size(genes,2)==28)
else
    disp('error size of genes')
    return
end

paso=.1;n=3;

%% frequency mesh
if n>0
    f=100*2.^(-(n-1)/2/(3*n))*2.^((0:3*n*6-1)/(3*n));
else
    f=linspace(100*2.^(-1/7),5000*2.^(1/7),18*abs(n)); %ojo, n=-1
totalemte desaconsejado
end
%% space mesh
x = 0:paso:2;
y = 0:paso:1.2;

%% Geometty of the crystal
a=1.2/7; %Mesh(paso de red)
[X,Y]=meshgrid(0:3,1:7);X=X(:).';Y=Y(:).';
centrosx=a*(X-3.5);centrosy=a*(Y-0.5);
radio=(genes*a)*.95/2; %OJOOOO
%end of the geometric definition

%Repeat two crystal up and two down(repeticiÛn del cristal dos arriba
y dos
%abajo)
centrosx=[centrosx centrosx centrosx centrosx centrosx];
centrosy=[-1.2*2+centrosy -1.2+centrosy centrosy 1.2+centrosy
1.2*2+centrosy];
radio=[radio radio radio radio radio];

%%


for kk=1:length(f)
    k= f(kk)*2*pi/340;
    pressure(:,:,kk)   =MS(centrosx,centrosy,radio,x,y,k,3);
    if pintar
        figure(10);close ;figure(10) %truco asqueroso.
        angulos=0:pi/10:2*pi;
        pcolor(x,y,20*log10(abs(pressure(:,:,kk))));shading
```

```
flat;colormap jet;
        title(num2str(round(f(kk))));colorbar;%set(gca,'CLim',[0 10])
        hold on
        for ii=1:length(centrosx);

patch(centrosx(ii)+radio(ii)*cos(angulos),centrosy(ii)+radio(ii)*sin(a
ngulos),'-k');
%                //Utilizamos este comando para asi poder recrear
nuestra figura geometrica.
            hold on
        end
        axis equal; hold off;axis([-1 2 0 1.2]);drawnow
    end
end

resultado=zeros(1,length(f));
for ii=1:length(f)
    patata=pressure(:,:,ii);
    resultado(ii)=sqrt(sum(sum(abs(patata).^2))/numel(patata));
end



ILbandafina=-10*log10(resultado);
ILtercios=-pasar_a_tercios(sqrt(10.^(-ILbandafina/10)),f);
redAtr=[-20;-20;-18;-16;-15;-14;-13;-12;-11;-9;-8;-9;-10;-11;-13;-15;-
16;-18]';
ILglobal=(-10*log10(sum(10.^((redAtr(1:end)-
ILtercios(1:end))/10))))+(10*log10(sum(10.^((redAtr(1:end)-0)/10))));



Return
```

Appendix **[2]**

```
close all;clear;clc


tic;
[ILbandafina,f,ILtercios,ILglobal]=calculosyprocesado(repmat([0.2 0.3
1 0.8],1,7));

% [ILbandafina,f,ILtercios,ILglobal]=calculosyprocesado(rand(1,28));
toc;

%ccreation vector of frequencies to draw the bands
fcent=100*2.^((0:17)/3)';
ff=[fcent*2^(-1/6) fcent*2^(-1/6) fcent*2^(+1/6)
fcent*2^(+1/6)]';ff=ff(:);
%ccreation vector of IL to draw the bands
ILterciosbandas=[zeros(18,1) ILtercios'  ILtercios'
zeros(18,1)]';ILterciosbandas=ILterciosbandas(:);

%Representation of the results
semilogx(f,ILbandafina,'o-g',ff,ILterciosbandas,'-
k',f,f*0+ILglobal,'r','LineWidth',3)
```

Appendix **[3]** In this Excel sheet we can observe the different values of the insertion loss that we can obtain with difereent radious of the SC.

Frequency(Hz)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)	IL(dB)
92,59	2,59	2,59	1,14	0,93	1,94	2,59	5,25	0,76	1,19	2,32	0,82	0,14	0,02	0,34	0,59
100,00	2,45	2,42	1,16	0,94	1,86	2,45	4,56	0,80	1,21	2,25	0,87	0,15	0,03	0,38	0,62
108,01	2,24	2,21	1,16	0,93	1,74	2,24	3,94	0,83	1,21	2,13	0,90	0,17	0,04	0,43	0,64
116,65	1,95	1,94	1,12	0,89	1,55	1,95	3,28	0,85	1,18	1,96	0,89	0,18	0,05	0,46	0,63
125,99	1,58	1,58	1,02	0,81	1,29	1,58	2,55	0,84	1,15	1,83	0,84	0,18	0,05	0,46	0,59
136,08	1,22	1,20	0,93	0,70	1,02	1,22	1,82	0,69	0,97	1,51	0,78	0,18	0,06	0,47	0,54
146,97	0,89	0,84	0,84	0,59	0,77	0,89	0,98	0,52	0,72	1,00	0,75	0,17	0,06	0,45	0,49
158,74	0,45	0,50	0,61	0,45	0,46	0,45	0,06	0,38	0,51	0,52	0,60	0,15	0,05	0,35	0,39
171,45	0,05	0,24	0,31	0,27	0,14	0,05	0,51	0,21	0,27	0,13	0,34	0,11	0,04	0,18	0,24
185,17	0,16	0,13	0,10	0,10	-0,06	0,16	2,46	-0,02	0,04	0,01	0,01	0,07	0,03	0,04	0,09
200,00	1,33	1,04	-0,01	0,00	0,29	1,33	2,98	-0,19	-0,13	0,48	-0,02	0,03	0,01	0,03	0,03
216,01	1,57	0,81	-0,12	0,07	1,04	1,57	3,38	0,04	0,13	-0,03	0,02	0,00	0,00	0,02	0,02
233,31	2,36	2,15	0,79	0,32	1,98	2,36	3,93	0,30	0,45	1,36	0,07	0,00	0,00	-0,01	0,11
251,98	3,37	2,05	0,73	0,62	2,45	3,37	4,02	0,66	0,88	2,16	0,29	0,02	0,00	0,06	0,64
272,16	3,36	2,32	0,93	0,96	2,79	3,36	3,77	1,14	1,37	2,57	0,60	0,06	0,01	0,18	0,68
293,95	2,71	2,57	1,24	1,26	2,53	2,71	1,95	1,46	1,65	1,92	0,90	0,13	0,03	0,35	0,91

317,48	2,07	2,46	1,21	1,36	2,02	2,07	0,63	1,36	1,49	1,30	1,07	0,20	0,05	0,49	0,99
342,90	1,49	1,92	0,86	1,06	1,47	1,49	3,44	1,17	1,14	0,14	1,01	0,24	0,07	0,55	0,77
370,35	1,10	1,27	0,51	0,72	0,64	1,10	4,30	0,06	0,07	1,91	0,69	0,22	0,07	0,47	0,55
400,00	2,47	1,99	0,33	0,35	0,75	2,47	3,80	0,35	0,74	1,44	0,20	0,13	0,05	0,26	0,43
432,02	1,77	1,25	0,07	0,23	1,26	1,77	4,31	1,14	1,45	0,91	0,07	0,03	0,02	0,03	0,01
466,61	1,74	2,82	0,00	1,26	2,30	1,74	6,64	1,01	1,35	1,88	0,78	0,03	0,00	0,04	-0,15
503,97	6,68	6,34	3,17	1,34	1,82	6,68	5,78	-0,50	-0,23	1,93	1,57	0,22	0,01	0,39	2,17
544,32	10,35	10,00	2,39	1,10	6,09	10,35	6,89	1,61	2,52	2,34	1,66	0,47	0,08	0,81	2,44
587,89	10,49	10,49	3,90	0,66	6,59	10,49	7,28	1,74	2,11	3,03	0,51	0,50	0,15	0,78	1,76
634,96	8,98	9,45	4,88	1,95	2,84	8,98	8,83	1,72	1,63	2,67	1,48	0,12	0,10	0,24	2,95
685,80	5,51	6,87	4,54	3,33	4,69	5,51	9,04	1,63	2,72	2,95	4,41	0,37	-0,03	0,30	2,91
740,70	8,31	8,94	5,94	6,70	6,56	8,31	9,21	2,41	5,34	5,15	5,22	2,69	0,26	1,97	2,14
800,00	7,01	7,48	4,99	6,41	4,31	7,01	9,03	2,78	6,26	5,09	3,23	5,12	1,30	3,06	1,70
864,05	7,42	6,50	2,95	7,28	5,93	7,42	8,66	2,68	6,63	7,20	6,99	6,57	2,52	3,25	2,56
933,22	9,07	10,13	7,15	7,43	8,57	9,07	12,66	2,91	7,58	7,10	4,52	7,20	3,17	3,64	4,52
1007,94	9,84	9,83	8,41	3,38	10,56	9,84	12,51	3,12	8,05	6,91	4,69	6,97	2,98	3,43	6,14
1088,63	3,71	3,21	4,67	0,71	10,53	3,71	12,87	2,89	6,73	7,19	4,21	5,42	2,36	1,52	3,52
1175,79	2,43	2,73	4,32	2,20	2,94	2,43	12,95	2,52	4,66	5,91	5,49	1,89	2,39	2,55	3,24
1269,92	2,65	3,17	0,49	3,71	4,72	2,65	13,53	1,85	4,87	2,56	1,44	0,28	2,00	3,57	0,48

1371,59	3,39	3,41	3,10	7,11	5,45	3,39	14,45	0,98	1,48	2,57	1,23	0,39	1,10	4,14	1,84
1481,40	4,97	3,32	4,48	7,18	6,44	4,97	14,63	0,87	0,72	2,38	0,40	0,15	0,27	1,83	3,90
1600,00	4,35	4,97	4,00	4,01	5,06	4,35	8,13	0,85	0,59	2,18	0,54	0,12	0,13	0,44	2,71
1728,10	3,07	3,75	2,90	0,91	0,87	3,07	3,17	1,94	1,01	1,38	0,34	0,08	0,07	0,55	2,29
1866,45	2,57	1,63	2,58	8,17	6,15	2,57	9,17	1,29	2,21	2,15	1,91	1,61	-0,28	0,39	1,98
2015,87	4,30	3,67	3,10	5,87	6,08	4,30	10,65	2,00	2,58	3,28	1,07	0,41	1,86	2,13	5,22
2177,26	3,64	4,61	3,63	4,98	7,87	3,64	9,00	2,78	6,12	8,26	7,78	6,47	1,08	1,77	3,46
2351,58	8,47	7,95	1,50	1,87	3,86	8,47	15,41	2,28	3,70	3,63	6,82	8,69	1,14	1,95	2,47
2539,84	7,10	7,28	4,49	4,28	5,09	7,10	15,07	2,30	7,30	5,05	3,17	12,44	1,23	1,76	2,51
2743,18	4,78	5,26	1,69	3,70	3,54	4,78	14,92	1,25	5,60	3,68	0,86	14,59	0,47	0,99	4,79
2962,80	5,60	3,20	5,62	2,59	5,11	5,60	14,13	1,19	2,12	2,10	0,75	3,90	0,56	0,81	5,01
3200,00	3,42	2,54	1,86	6,30	3,75	3,42	1,66	1,70	3,92	2,85	1,93	5,13	0,96	0,90	3,87
3456,19	6,05	5,09	4,30	4,19	4,24	6,05	4,74	1,84	2,21	2,62	1,20	1,11	0,78	0,98	2,57
3732,89	4,87	4,69	2,91	3,05	3,86	4,87	1,46	1,45	1,76	2,30	2,33	5,45	1,14	1,11	4,76
4031,75	2,36	1,73	2,78	2,95	2,25	2,36	1,48	1,46	2,67	1,95	2,01	1,96	1,44	1,06	2,92
4354,53	2,92	2,43	1,29	2,26	2,47	2,92	3,56	1,75	1,52	2,04	1,57	0,83	0,72	0,99	3,89
4703,15	2,90	2,61	1,89	2,25	2,67	2,90	1,75	1,05	1,09	1,44	1,35	0,22	0,41	0,69	1,67
5079,68	1,82	2,00	1,09	1,91	1,85	1,82	2,45	1,03	2,20	2,40	1,76	1,47	0,65	0,76	1,93
5486,36	1,15	1,13	1,30	1,68	1,63	1,15	0,57	1,39	1,40	0,67	0,85	0,52	0,64	0,56	2,07

Appendix **[4]**

```
function
[ILbandafina,f,ILtercios,ILglobal]=calculosyprocesado(genes,pintar)
if nargin<2
    pintar=0;
end
% // If we don't have the value of pintar,we force it to be 0.

if (size(genes,1)==1)&&(size(genes,2)==28)
else
    disp('error size of genes')
    return
end

paso=.1;n=3;

%% frequency mesh
if n>0
    f=100*2.^(-(n-1)/2/(3*n))*2.^((0:3*n*6-1)/(3*n));
else
    f=linspace(100*2.^(-1/7),5000*2.^(1/7),18*abs(n)); %ojo, n=-1
totalemte desaconsejado
end
%% space mesh
x = 0:paso:2;
y = 0:paso:1.2;

%% Geometty of the crystal
a=1.2/7; %Mesh(paso de red)
[X,Y]=meshgrid(0:3,1:7);X=X(:).';Y=Y(:).';
centrosx=a*(X-3.5);centrosy=a*(Y-0.5);
radio=(genes*a)*.95/2; %0J0000
%end of the geometric definition

%Repeat two crystal up and two down(repeticiÛn del cristal dos arriba
y dos
%abajo)
centrosx=[centrosx centrosx centrosx centrosx centrosx];
centrosy=[-1.2*2+centrosy -1.2+centrosy centrosy 1.2+centrosy
1.2*2+centrosy];
radio=[radio radio radio radio radio];

%%




for kk=28:36
    k= f(kk)*2*pi/340;
    pressure(:,:,kk)    =MS(centrosx,centrosy,radio,x,y,k,3);
    if pintar
        figure(10);close ;figure(10) %truco asqueroso.
        angulos=0:pi/10:2*pi;
        pcolor(x,y,20*log10(abs(pressure(:,:,kk))));shading
flat;colormap jet;
        title(num2str(round(f(kk))));colorbar;%set(gca,'CLim',[0 10])
        hold on
```

```
        for ii=1:length(centrosx);
patch(centrosx(ii)+radio(ii)*cos(angulos),centrosy(ii)+radio(ii)*sin(a
ngulos),'-k');
%               //Utilizamos este comando para asi poder recrear
nuestra figura geometrica.
            hold on
        end
        axis equal; hold off;axis([-1 2 0 1.2]);drawnow
    end
end

resultado=zeros(1,length(f));
for ii=28:36
    patata=pressure(:,:,ii);
    resultado(ii)=sqrt(sum(sum(abs(patata).^2))/numel(patata));
end



ILbandafina=-10*log10(resultado);
ILtercios=-pasar_a_tercios(sqrt(10.^(-ILbandafina/10)),f);
redAtr=[-20;-20;-18;-16;-15;-14;-13;-12;-11;-9;-8;-9;-10;-11;-13;-15;-
16;-18]';
ILglobal=(-10*log10(sum(10.^((redAtr(10:12)-
ILtercios(10:12))/10))))+(10*log10(sum(10.^((redAtr(10:12)-0)/10))));



Return
```

Appendix **[5]**

------ evMOGA Algorithm -------
######### evMOGA initialization
Value assigned:
eMOGA.searchSpace_dim=28
Default value assigned:
eMOGA.dd_ini=0.25
Default value assigned:
eMOGA.dd_fin=0.1
Default value assigned:
eMOGA.Pm=0.2
Default value assigned:
Sigma_Pm_ini=20
Default value assigned:
Sigma_Pm_fin=0.1

######### generation 3
Nind_A=1
Objectives min values: -9.4208
######### generation 4

Default value assigned:
Nind_GA=8
Value assigned for every objective:
n_div=[200]
Additional objective function parameters empty
######### Generating initial population
######### Empty initial subpopulation
######### generation 1
Nind_A=1
Objectives min values: -9.1972
######### generation 2
Nind_A=1
Objectives min values: -9.2178

Nind_A=1
Objectives min values: -9.4547
######### generation 5

Nind_A=1
Objectives min values: -9.4858
######### generation 6
Nind_A=1
Objectives min values: -9.5317
######### generation 7
Nind_A=1
Objectives min values: -9.608
######### generation 8
Nind_A=1
Objectives min values: -9.608
######### generation 9
Nind_A=1
Objectives min values: -9.6496
######### generation 10
Nind_A=1
Objectives min values: -9.6496
######### generation 11
Nind_A=1
Objectives min values: -9.7374
######### generation 12
Nind_A=1
Objectives min values: -9.7374
######### generation 13
Nind_A=1
Objectives min values: -9.7374
######### generation 14
Nind_A=1
Objectives min values: -9.7391
######### generation 15
Nind_A=1
Objectives min values: -9.7391
######### generation 16
Nind_A=1
Objectives min values: -9.7391
######### generation 17
Nind_A=1
Objectives min values: -9.7502
######### generation 18
Nind_A=1
Objectives min values: -9.7502
######### generation 19
Nind_A=1
Objectives min values: -9.7502
######### generation 20
Nind_A=1
Objectives min values: -9.7717
######### generation 21
Nind_A=1
Objectives min values: -9.7833
######### generation 22
Nind_A=1
Objectives min values: -9.9278
######### generation 23
Nind_A=1
Objectives min values: -9.9286
######### generation 24
Nind_A=1
Objectives min values: -9.9432
######### generation 25
Nind_A=1
Objectives min values: -9.9477
######### generation 26
Nind_A=1
Objectives min values: -9.9635
######### generation 27
Nind_A=1
Objectives min values: -9.9635
######### generation 28
Nind_A=1
Objectives min values: -10.1334
######### generation 29
Nind_A=1
Objectives min values: -10.1334
######### generation 30
Nind_A=1
Objectives min values: -10.1775
######### generation 31
Nind_A=1
Objectives min values: -10.1842
######### generation 32
Nind_A=1
Objectives min values: -10.1935
######### generation 33
Nind_A=1
Objectives min values: -10.3034
######### generation 34
Nind_A=1
Objectives min values: -10.3554
######### generation 35
Nind_A=1
Objectives min values: -10.3554
######### generation 36
Nind_A=1
Objectives min values: -10.3567
######### generation 37
Nind_A=1
Objectives min values: -10.3567
######### generation 38
Nind_A=1

Objectives min values: -10.3735
######### generation 39
Nind_A=1
Objectives min values: -10.4822
######### generation 40
Nind_A=1
Objectives min values: -10.5645
######### generation 41
Nind_A=1
Objectives min values: -10.7343
######### generation 42
Nind_A=1
Objectives min values: -10.9442
######### generation 43
Nind_A=1
Objectives min values: -11.0229
######### generation 44
Nind_A=1
Objectives min values: -11.067
######### generation 45
Nind_A=1
Objectives min values: -11.0746
######### generation 46
Nind_A=1
Objectives min values: -11.0746
######### generation 47
Nind_A=1
Objectives min values: -11.0746
######### generation 48
Nind_A=1
Objectives min values: -11.0746
######### generation 49
Nind_A=1
Objectives min values: -11.0746
######### generation 50
Nind_A=1
Objectives min values: -11.0746
######### generation 51
Nind_A=1
Objectives min values: -11.0746
######### generation 52
Nind_A=1
Objectives min values: -11.0746
######### generation 53
Nind_A=1
Objectives min values: -11.1232
######### generation 54
Nind_A=1
Objectives min values: -11.1232
######### generation 55
Nind_A=1
Objectives min values: -11.1232
######### generation 56
Nind_A=1
Objectives min values: -11.149
######### generation 57
Nind_A=1
Objectives min values: -11.149
######### generation 58
Nind_A=1
Objectives min values: -11.1498
######### generation 59
Nind_A=1
Objectives min values: -11.1498
######### generation 60
Nind_A=1
Objectives min values: -11.1498
######### generation 61
Nind_A=1
Objectives min values: -11.1498
######### generation 62
Nind_A=1
Objectives min values: -11.1566
######### generation 63
Nind_A=1
Objectives min values: -11.1566
######### generation 64
Nind_A=1
Objectives min values: -11.1566
######### generation 65
Nind_A=1
Objectives min values: -11.1566
######### generation 66
Nind_A=1
Objectives min values: -11.1566
######### generation 67
Nind_A=1
Objectives min values: -11.1566
######### generation 68
Nind_A=1
Objectives min values: -11.1566
######### generation 69
Nind_A=1
Objectives min values: -11.1566
######### generation 70
Nind_A=1
Objectives min values: -11.1566
######### generation 71
Nind_A=1
Objectives min values: -11.1566

######### generation 72
Nind_A=1
Objectives min values: -11.1566
######### generation 73
Nind_A=1
Objectives min values: -11.1566
######### generation 74
Nind_A=1
Objectives min values: -11.1566
######### generation 75
Nind_A=1
Objectives min values: -11.1566
######### generation 76
Nind_A=1
Objectives min values: -11.18
######### generation 77
Nind_A=1
Objectives min values: -11.18
######### generation 78
Nind_A=1
Objectives min values: -11.1803
######### generation 79
Nind_A=1
Objectives min values: -11.1803
######### generation 80
Nind_A=1
Objectives min values: -11.1803
######### generation 81
Nind_A=1
Objectives min values: -11.1803
######### generation 82
Nind_A=1
Objectives min values: -11.1803
######### generation 83
Nind_A=1
Objectives min values: -11.1845
######### generation 84
Nind_A=1
Objectives min values: -11.1845
######### generation 85
Nind_A=1
Objectives min values: -11.1845
######### generation 86
Nind_A=1
Objectives min values: -11.1845
######### generation 87
Nind_A=1
Objectives min values: -11.1845
######### generation 88
Nind_A=1
Objectives min values: -11.1845
######### generation 89
Nind_A=1
Objectives min values: -11.1845
######### generation 90
Nind_A=1
Objectives min values: -11.1845
######### generation 91
Nind_A=1
Objectives min values: -11.1845
######### generation 92
Nind_A=1
Objectives min values: -11.1845
######### generation 93
Nind_A=1
Objectives min values: -11.1845
######### generation 94
Nind_A=1
Objectives min values: -11.1845
######### generation 95
Nind_A=1
Objectives min values: -11.1845
######### generation 96
Nind_A=1
Objectives min values: -11.1845
######### generation 97
Nind_A=1
Objectives min values: -11.1845
######### generation 98
Nind_A=1
Objectives min values: -11.1845
######### generation 99
Nind_A=1
Objectives min values: -11.1845
######### generation 100
Nind_A=1
Objectives min values: -11.1845

RESULT
Nind_A=1
Objectives min values: -11.1845

Appendix **[6]**

------ evMOGA Algorithm -------
######### evMOGA initialization
Value assigned:
eMOGA.searchSpace_dim=28
Default value assigned:
eMOGA.dd_ini=0.25
Default value assigned:
eMOGA.dd_fin=0.1
Default value assigned:
eMOGA.Pm=0.2
Default value assigned:
Sigma_Pm_ini=20
Default value assigned:
Sigma_Pm_fin=0.1
Default value assigned:
Nind_GA=8
Value assigned for every objective:
n_div=[200 200]
Additional objective function parameters empty
######### Generating initial population
######### Adding subpopulation of 4 individuals
######### generation 1
Nind_A=1
Objectives min values: -11.3524 -8.46254
######### generation 2
Nind_A=1
Objectives min values: -11.3524 -8.46254
######### generation 3
Nind_A=2
Objectives min values: -11.3591 -8.46254
######### generation 4
Nind_A=3
Objectives min values: -11.3592 -8.47961
######### generation 5
Nind_A=3
Objectives min values: -11.3592 -8.47961
######### generation 6
Nind_A=3
Objectives min values: -11.3592 -8.47961
######### generation 7
Nind_A=4
Objectives min values: -11.366 -8.47961
######### generation 8
Nind_A=2
Objectives min values: -11.3668 -8.47961
######### generation 9
Nind_A=2
Objectives min values: -11.3668 -8.47961
######### generation 10
Nind_A=2
Objectives min values: -11.3668 -8.47961
######### generation 11
Nind_A=4
Objectives min values: -11.3668 -8.48083
######### generation 12
Nind_A=5
Objectives min values: -11.3668 -8.48083
######### generation 13
Nind_A=5
Objectives min values: -11.3668 -8.48083
######### generation 14
Nind_A=4
Objectives min values: -11.3829 -8.48083
######### generation 15
Nind_A=4
Objectives min values: -11.3829 -8.48083
######### generation 16
Nind_A=4
Objectives min values: -11.3881 -8.48083
######### generation 17
Nind_A=4
Objectives min values: -11.3881 -8.48083

######### generation 18
Nind_A=4
Objectives min values: -11.3881 -8.48083
######### generation 19
Nind_A=4
Objectives min values: -11.3881 -8.48731
######### generation 20
Nind_A=5
Objectives min values: -11.3881 -8.48731
######### generation 21
Nind_A=5
Objectives min values: -11.3881 -8.48731
######### generation 22
Nind_A=5
Objectives min values: -11.3881 -8.48731
######### generation 23
Nind_A=5
Objectives min values: -11.3881 -8.48731
######### generation 24
Nind_A=5
Objectives min values: -11.3881 -8.48731
######### generation 25
Nind_A=6
Objectives min values: -11.3881 -8.48731
######### generation 26
Nind_A=6
Objectives min values: -11.3881 -8.48731
######### generation 27
Nind_A=6
Objectives min values: -11.3881 -8.48815
######### generation 28
Nind_A=6
Objectives min values: -11.3881 -8.48815
######### generation 29
Nind_A=6
Objectives min values: -11.3881 -8.48815
######### generation 30
Nind_A=7
Objectives min values: -11.3881 -8.48815
######### generation 31
Nind_A=6
Objectives min values: -11.4014 -8.48815
######### generation 32
Nind_A=7
Objectives min values: -11.4014 -8.48815
######### generation 33
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 34
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 35
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 36
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 37
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 38
Nind_A=8
Objectives min values: -11.4014 -8.48815
######### generation 39
Nind_A=9
Objectives min values: -11.4014 -8.48815
######### generation 40
Nind_A=9
Objectives min values: -11.4014 -8.48815
######### generation 41
Nind_A=6
Objectives min values: -11.4014 -8.48815
######### generation 42
Nind_A=6
Objectives min values: -11.407 -8.48815

######### generation 43
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 44
Nind_A=8
Objectives min values: -11.407 -
8.48815
######### generation 45
Nind_A=8
Objectives min values: -11.407 -
8.48815
######### generation 46
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 47
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 48
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 49
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 50
Nind_A=7
Objectives min values: -11.407 -
8.48815
######### generation 51
Nind_A=9
Objectives min values: -11.407 -
8.48815
######### generation 52
Nind_A=9
Objectives min values: -11.407 -
8.48815
######### generation 53
Nind_A=10
Objectives min values: -11.4083 -
8.48815
######### generation 54
Nind_A=10
Objectives min values: -11.4083 -
8.48815
######### generation 55
Nind_A=10
Objectives min values: -11.4083 -
8.48815
######### generation 56
Nind_A=11
Objectives min values: -11.4083 -
8.48815
######### generation 57
Nind_A=11
Objectives min values: -11.4083 -
8.48815
######### generation 58
Nind_A=11
Objectives min values: -11.4083 -
8.48815
######### generation 59
Nind_A=10
Objectives min values: -11.4083 -
8.48864
######### generation 60
Nind_A=11
Objectives min values: -11.4083 -
8.48864
######### generation 61
Nind_A=12
Objectives min values: -11.4083 -
8.48864
######### generation 62
Nind_A=13
Objectives min values: -11.4083 -
8.48864
######### generation 63
Nind_A=13
Objectives min values: -11.4083 -
8.48864
######### generation 64
Nind_A=11
Objectives min values: -11.4083 -
8.48864
######### generation 65
Nind_A=11
Objectives min values: -11.4083 -
8.48864
######### generation 66
Nind_A=11
Objectives min values: -11.4083 -
8.48864
######### generation 67
Nind_A=11
Objectives min values: -11.4083 -
8.48864

######### generation 68
Nind_A=12
Objectives min values: -11.4083 -8.48864
######### generation 69
Nind_A=11
Objectives min values: -11.4083 -8.50294
######### generation 70
Nind_A=11
Objectives min values: -11.4083 -8.50294
######### generation 71
Nind_A=12
Objectives min values: -11.4091 -8.50294
######### generation 72
Nind_A=12
Objectives min values: -11.4091 -8.50294
######### generation 73
Nind_A=13
Objectives min values: -11.4091 -8.50294
######### generation 74
Nind_A=13
Objectives min values: -11.4091 -8.50294
######### generation 75
Nind_A=13
Objectives min values: -11.4091 -8.50294
######### generation 76
Nind_A=14
Objectives min values: -11.4091 -8.50294
######### generation 77
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 78
Nind_A=9
Objectives min values: -11.4104 -8.50294
######### generation 79
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 80
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 81
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 82
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 83
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 84
Nind_A=11
Objectives min values: -11.4104 -8.50294
######### generation 85
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 86
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 87
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 88
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 89
Nind_A=14
Objectives min values: -11.4104 -8.50294
######### generation 90
Nind_A=14
Objectives min values: -11.4104 -8.50294
######### generation 91
Nind_A=13
Objectives min values: -11.4104 -8.50294
######### generation 92
Nind_A=13
Objectives min values: -11.4104 -8.50294

######### generation 93
Nind_A=13
Objectives min values: -11.4104 -
8.50294
######### generation 94
Nind_A=15
Objectives min values: -11.4117 -
8.50294
######### generation 95
Nind_A=16
Objectives min values: -11.4211 -
8.50294
######### generation 96
Nind_A=16
Objectives min values: -11.4211 -
8.50294
######### generation 97
Nind_A=16
Objectives min values: -11.4211 -
8.50294
######### generation 98
Nind_A=18
Objectives min values: -11.4211 -
8.50294
######### generation 99
Nind_A=21
Objectives min values: -11.4211 -
8.50294
######### generation 100
Nind_A=21
Objectives min values: -11.4211 -
8.50294

RESULT
Nind_A=21
Objectives min values: -11.4211 -
8.50294

Appendix **[7]**

Values of the radious obtained that our SC should have for the bands of 1kHz and 2kHz

Indivuduals																												
1	1,00	1,00	0,99	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	1,00
2	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	1,00	1,00	0,99	0,99	0,99	0,99	0,99	1,00	0,99	0,99	1,00	0,99	0,99	1,00	1,00	0,99	0,99	0,97	1,00	0,99
3	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	0,99
4	0,99	0,99	0,98	1,00	0,98	1,00	1,00	0,99	1,00	1,00	0,99	0,98	0,99	0,98	1,00	0,99	0,99	0,99	1,00	0,99	0,98	1,00	1,00	0,99	0,97	0,98	1,00	0,99
5	1,00	1,00	0,99	1,00	0,99	1,00	1,00	0,99	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,98	1,00	1,00
6	0,99	0,98	0,98	0,99	0,98	0,98	0,99	0,98	1,00	1,00	0,99	0,97	0,99	0,97	0,99	0,99	0,98	0,99	0,99	0,99	0,98	0,99	1,00	0,98	0,97	0,97	1,00	0,98
7	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	1,00	0,99	0,99	0,99	0,99	0,99	1,00	0,99	0,99	1,00	0,99	0,99	1,00	1,00	0,99	0,98	0,97	0,99	0,99
8	0,99	0,98	0,98	0,99	0,98	0,98	0,99	0,98	1,00	1,00	0,99	0,97	0,99	0,97	0,99	0,99	0,98	0,99	1,00	0,99	0,98	0,99	1,00	0,98	0,97	0,97	1,00	0,98
9	1,00	1,00	0,99	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	1,00
10	0,99	0,98	0,98	0,99	0,98	0,98	0,99	0,98	1,00	1,00	0,99	0,97	0,99	0,97	0,99	0,99	0,98	0,99	1,00	0,99	0,97	0,99	1,00	0,98	0,97	0,97	1,00	0,97
11	0,99	0,99	0,99	1,00	0,99	0,99	0,99	0,99	1,00	1,00	1,00	0,99	1,00	0,99	1,00	1,00	0,99	0,99	1,00	0,99	0,99	1,00	1,00	0,99	0,99	0,97	0,99	0,99
12	0,99	0,98	0,98	0,99	0,98	0,98	0,99	0,98	1,00	1,00	0,99	0,97	0,99	0,97	0,99	0,99	0,98	0,99	1,00	0,99	0,98	0,99	1,00	0,98	0,97	0,97	1,00	0,98
13	0,98	0,98	0,98	0,98	0,96	0,97	0,98	0,96	0,98	0,98	0,98	0,98	0,99	0,98	0,98	1,00	0,99	0,99	1,00	0,97	0,98	0,99	0,99	0,98	0,96	0,95	0,99	0,98
14	1,00	1,00	0,99	1,00	0,99	1,00	1,00	0,99	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,99	0,98	1,00	1,00
15	0,99	0,99	0,99	1,00	0,99	0,99	0,99	0,99	1,00	1,00	1,00	0,99	0,99	1,00	1,00	1,00	1,00	0,99	1,00	0,99	1,00	1,00	1,00	0,99	0,99	0,97	1,00	0,99
16	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	1,00	1,00	0,99	0,99	0,99	0,99	0,99	1,00	0,99	0,99	1,00	0,99	0,99	1,00	1,00	0,99	0,98	0,97	1,00	0,99
17	1,00	1,00	0,99	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	1,00
18	1,00	0,99	1,00	0,99	1,00	1,00	1,00	0,99	1,00	1,00	1,00	0,98	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,00	0,99	0,97	1,00	1,00
19	0,99	0,99	0,99	1,00	0,99	1,00	1,00	0,99	1,00	1,00	1,00	0,99	1,00	1,00	1,00	1,00	0,99	0,99	1,00	0,99	0,99	1,00	1,00	0,99	0,99	0,97	0,99	0,99
20	0,99	0,99	0,99	1,00	0,99	0,99	0,99	0,99	1,00	1,00	1,00	0,99	0,99	1,00	1,00	1,00	1,00	0,99	1,00	0,99	1,00	1,00	1,00	0,99	0,99	0,97	1,00	0,99
21	0,99	0,98	0,98	0,99	0,98	0,98	0,99	0,98	1,00	1,00	0,99	0,97	0,99	0,97	0,99	0,99	0,98	0,99	0,99	0,99	0,98	0,99	1,00	0,98	0,97	0,97	1,00	0,98

Appendix **[8]**

------ evMOGA Algorithm -------
######### evMOGA initialization
Value assigned:
eMOGA.searchSpace_dim=28
Default value assigned:
eMOGA.dd_ini=0.25
Default value assigned:
eMOGA.dd_fin=0.1
Default value assigned:
eMOGA.Pm=0.2
Default value assigned:
Sigma_Pm_ini=20
Default value assigned:
Sigma_Pm_fin=0.1
Default value assigned:
Nind_GA=8
Value assigned for every objective:
n_div=[200 200]
Additional objective function parameters empty
######### Generating initial population
######### Adding subpopulation of 4 individuals
######### generation 1
Nind_A=1
Objectives min values: -11.3524 -6.26657
######### generation 2
Nind_A=1
Objectives min values: -11.3524 -6.26657
######### generation 3
Nind_A=2
Objectives min values: -11.3531 -6.26657
######### generation 4
Nind_A=2
Objectives min values: -11.3573 -6.26657
######### generation 5
Nind_A=4
Objectives min values: -11.3617 -6.26657
######### generation 6
Nind_A=6
Objectives min values: -11.3643 -6.26657
######### generation 7
Nind_A=6
Objectives min values: -11.3643 -6.26657
######### generation 8
Nind_A=4
Objectives min values: -11.3675 -6.26657
######### generation 9
Nind_A=4
Objectives min values: -11.3675 -6.26657
######### generation 10
Nind_A=5
Objectives min values: -11.369 -6.26657
######### generation 11
Nind_A=5
Objectives min values: -11.369 -6.26657
######### generation 12
Nind_A=5
Objectives min values: -11.369 -6.26657
######### generation 13
Nind_A=5
Objectives min values: -11.369 -6.26657
######### generation 14
Nind_A=7
Objectives min values: -11.3828 -6.26657
######### generation 15
Nind_A=7
Objectives min values: -11.3828 -6.26657
######### generation 16
Nind_A=7
Objectives min values: -11.3828 -6.26657
######### generation 17
Nind_A=9
Objectives min values: -11.3828 -6.26657
######### generation 18

Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 19
Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 20
Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 21
Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 22
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 23
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 24
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 25
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 26
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 27
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 28
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 29
Nind_A=8
Objectives min values: -11.3828 -
6.26657
######### generation 30
Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 31
Nind_A=10
Objectives min values: -11.3828 -
6.26657
######### generation 32
Nind_A=11
Objectives min values: -11.3828 -
6.26657
######### generation 33
Nind_A=11
Objectives min values: -11.3828 -
6.26657
######### generation 34
Nind_A=11
Objectives min values: -11.3828 -
6.26657
######### generation 35
Nind_A=11
Objectives min values: -11.3828 -
6.26657
######### generation 36
Nind_A=11
Objectives min values: -11.3828 -
6.26657
######### generation 37
Nind_A=9
Objectives min values: -11.3828 -
6.26657
######### generation 38
Nind_A=9
Objectives min values: -11.384 -
6.26657
######### generation 39
Nind_A=9
Objectives min values: -11.384 -
6.26657
######### generation 40
Nind_A=9
Objectives min values: -11.384 -
6.26657
######### generation 41
Nind_A=9
Objectives min values: -11.384 -
6.26657
######### generation 42
Nind_A=9
Objectives min values: -11.384 -
6.26657

######### generation 43
Nind_A=9
Objectives min values: -11.384 -6.26657
######### generation 44
Nind_A=10
Objectives min values: -11.384 -6.26657
######### generation 45
Nind_A=10
Objectives min values: -11.384 -6.26657
######### generation 46
Nind_A=11
Objectives min values: -11.384 -6.26657
######### generation 47
Nind_A=11
Objectives min values: -11.4084 -6.26657
######### generation 48
Nind_A=11
Objectives min values: -11.4084 -6.26657
######### generation 49
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 50
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 51
Nind_A=12
Objectives min values: -11.4084 -6.26657
######### generation 52
Nind_A=12
Objectives min values: -11.4084 -6.26657
######### generation 53
Nind_A=12
Objectives min values: -11.4084 -6.26657
######### generation 54
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 55
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 56
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 57
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 58
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 59
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 60
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 61
Nind_A=10
Objectives min values: -11.4084 -6.26657
######### generation 62
Nind_A=11
Objectives min values: -11.4084 -6.26657
######### generation 63
Nind_A=11
Objectives min values: -11.4084 -6.26657
######### generation 64
Nind_A=12
Objectives min values: -11.4084 -6.26657
######### generation 65
Nind_A=12
Objectives min values: -11.4084 -6.26657
######### generation 66
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 67
Nind_A=13
Objectives min values: -11.4084 -6.26657

######### generation 68
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 69
Nind_A=13
Objectives min values: -11.4084 -6.26657
######### generation 70
Nind_A=14
Objectives min values: -11.4084 -6.26657
######### generation 71
Nind_A=14
Objectives min values: -11.4084 -6.26657
######### generation 72
Nind_A=15
Objectives min values: -11.4084 -6.26657
######### generation 73
Nind_A=16
Objectives min values: -11.4084 -6.26657
######### generation 74
Nind_A=17
Objectives min values: -11.4096 -6.26657
######### generation 75
Nind_A=17
Objectives min values: -11.4096 -6.26657
######### generation 76
Nind_A=18
Objectives min values: -11.4096 -6.26657
######### generation 77
Nind_A=18
Objectives min values: -11.4096 -6.26657
######### generation 78
Nind_A=18
Objectives min values: -11.4096 -6.26657
######### generation 79
Nind_A=18
Objectives min values: -11.4096 -6.26657
######### generation 80
Nind_A=19
Objectives min values: -11.4096 -6.26657
######### generation 81
Nind_A=19
Objectives min values: -11.4096 -6.26657
######### generation 82
Nind_A=19
Objectives min values: -11.4096 -6.26657
######### generation 83
Nind_A=20
Objectives min values: -11.4096 -6.26657
######### generation 84
Nind_A=21
Objectives min values: -11.4096 -6.26657
######### generation 85
Nind_A=21
Objectives min values: -11.4096 -6.26657
######### generation 86
Nind_A=21
Objectives min values: -11.4096 -6.26657
######### generation 87
Nind_A=15
Objectives min values: -11.4096 -6.26657
######### generation 88
Nind_A=15
Objectives min values: -11.4096 -6.26657
######### generation 89
Nind_A=14
Objectives min values: -11.4141 -6.26657
######### generation 90
Nind_A=14
Objectives min values: -11.4141 -6.26657
######### generation 91
Nind_A=14
Objectives min values: -11.4141 -6.26657
######### generation 92
Nind_A=14
Objectives min values: -11.4141 -6.26657

########## generation 93
Nind_A=14
Objectives min values: -11.4141 -
6.26657
########## generation 94
Nind_A=14
Objectives min values: -11.4141 -
6.26657
########## generation 95
Nind_A=14
Objectives min values: -11.4141 -
6.26657
########## generation 96
Nind_A=14
Objectives min values: -11.4141 -
6.26657
########## generation 97
Nind_A=14
Objectives min values: -11.4141 -
6.26657
########## generation 98
Nind_A=15
Objectives min values: -11.4141 -
6.26657
########## generation 99
Nind_A=16
Objectives min values: -11.4161 -
6.26657
########## generation 100
Nind_A=14
Objectives min values: -11.4161 -
6.26657

RESULT
Nind_A=14
Objectives min values: -11.4161 -
6.26657

Appendix **[9]**

Values of the radious obtained that our SC should have for the bands of 1kHz and 500Hz

Individuals														
1	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	1,00
3	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
4	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	1,00
5	1,00	1,00	0,99	0,98	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
6	0,98	0,99	0,99	0,99	0,99	0,99	0,98	0,98	0,99	0,98	0,99	0,99	0,99	0,98
7	0,97	0,99	0,97	0,98	0,98	0,97	0,97	0,97	0,97	0,96	0,97	0,98	0,98	0,97
8	0,97	0,99	0,98	0,98	0,98	0,97	0,97	0,96	0,97	0,98	0,97	0,97	0,98	0,96
9	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	1,00	1,00	0,99
10	0,97	0,99	0,99	0,98	0,99	0,98	0,97	0,97	0,98	0,97	0,97	0,99	0,98	0,97
11	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
12	0,98	1,00	0,99	0,99	0,99	0,99	0,98	0,97	0,98	0,98	0,98	1,00	0,98	0,98
13	0,98	1,00	0,99	1,00	0,99	1,00	0,97	0,97	1,00	0,98	0,99	1,00	0,98	0,97
14	0,98	1,00	0,99	0,99	0,99	0,98	0,98	0,97	0,98	0,97	0,98	0,99	0,98	0,97

Individuals														
1	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	1,00
3	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
4	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00	1,00
5	1,00	1,00	0,98	1,00	1,00	1,00	1,00	1,00	0,99	1,00	1,00	1,00	0,97	1,00
6	0,99	0,99	0,98	0,99	0,99	0,99	0,98	1,00	0,99	0,97	0,99	0,98	0,98	1,00
7	0,97	0,99	0,96	0,98	0,98	0,98	0,97	0,99	0,98	0,95	0,98	0,96	0,96	1,00
8	0,98	0,99	0,97	0,98	0,98	0,98	0,96	0,98	0,98	0,95	0,97	0,97	0,98	0,99
9	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,96	1,00	0,99	0,98	1,00
10	0,97	0,99	0,96	0,99	0,98	0,98	0,97	1,00	0,98	0,95	0,99	0,97	0,97	1,00
11	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	1,00	1,00
12	0,98	0,99	0,97	1,00	0,99	0,99	0,98	1,00	0,99	0,96	0,98	0,98	0,98	1,00
13	0,98	1,00	0,97	0,99	1,00	0,98	1,00	1,00	1,00	0,97	1,00	0,98	0,98	1,00
14	0,97	1,00	0,96	0,99	0,98	0,99	0,97	1,00	0,99	0,95	0,99	0,97	0,97	1,00

Bachelorarbeit

Fakultät für
Informations-, Medien-
und Elektrotechnik

Technology
Arts Sciences
TH Köln

Optimization of the performance of acoustic screens based on sonic crystals

Verfasst von: David Alvarez Hurtado

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Studiengang: Bachelor Elektrotechnik

Erstgutachter/-in: Christoph Pörschmann

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Abgabefrist: 29.09.2017

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