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REVIEW THE TECHNIQUE FOR ACOUSTIC SUPERLENS USING SINGLE PHASE METAMATERIALS

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Abstract

We recommend using a low-density single-phase super lens to concentrate sound past the diffraction limit. The star-shaped steel lattice that makes up the super lens makes it possible for it to make aberrant dispersive effects. Negative parameter indices can be used to measure the size of these effects. An analysis of the band structure of metamaterials found that star-shaped metamaterials have double-negative index features that could help with these effects for sound in water. Simulations have shown that a single-phase solid lens with a spatial resolution of about 0.39 nm may be able to focus sound well. Because it has a low density and is solid at the same time, this superlens can be used in liquid environments.

Keywords: Acoustic Superlens, Single Phase Metamaterials , low-frequency

Introduction

Despite having a lower data capacity, low-frequency signalling and communication may cover a larger area because it uses longer wavelengths. This allows for greater flexibility. This benefit can be attributed, in no uncertain terms, to the low frequency. Even in the realm of animals, this advantage, which presents itself as a broader range of motion, is utilised to the fullest extent possible. It is believed that certain animals, such as elephants, make use of infrasonic frequencies in order to communicate with other members of their herd or with their mates over a wider. Tracking or recovering low-frequency signals, on the other hand, requires first isolating the signals from the background noise that they are surrounded by. Low-frequency sounds can be produced by a variety of sources, including machine vibrations and shipping noises, as well as by natural occurrences such as wind, tide, rain, seismic vibrations, and so on. Tracking variations in the noise spectral density in various bandwidths not only makes it feasible to recognise natural phenomena like earthquakes and rainfall patterns, but it can also be used to quantify these occurrences[1]. In addition, there is an interest in the signal by itself. Because of all of these factors, it is necessary to make use of frequency selective devices that are able to function within the low frequency range and satisfy the particular performance criteria that are associated with each application. This list of devices may also contain demultiplexers, high-pass or low-pass filters, or noise-cancelling band-pass filters. All of these filtering options may also be used. Using these filters and demultiplexers, they were able to differentiate between the various frequency bands and send them to distinct ports so that the data could be further processed. When it comes to underwater communication equipment, researchers have discovered that the levels of ambient noise in the ocean, regardless of whether the noise was caused by humans or by natural processes (biological or geophysical), are higher in shallower oceans that are closer to the coastlines. They change depending on the amount of time that has passed, the environment in which they take place, and the number of times that they occur. We explore the most prevalent noise generators found in aquatic habitats as well as the frequency bands that their emissions fall into. In the lower frequency range, acoustic communication is recommended over electromagnetic wave communication for use in applications involving aquatic environments. This is mostly because electromagnetic wave transmission requires the use of antennas with a huge surface area. Because submerged vehicles are unable to afford to buy and tow huge antennae, which are essential for contact with them, this link can only function as a communication link that can send information in one direction. In the field of acoustics, it is essential for naval and oceanographic systems to have the capacity to differentiate sonar pings and other important acoustic signals from background noise. According [2] the characterization of ambient noise is increasingly being used for a wide range of purposes, ranging from the observation of weather and climate to the assessment of marine life, their distribution and behaviour, as well as determining where and how the noise is coming from. These applications can be found in a variety of fields, including meteorology and climate science, marine biology, and environmental science. Fourier analysis of time series data is utilised by each and every one of them. In naval applications, it is standard practise to utilise electrical band-pass filters of the second order or more complicated filters of higher order to reduce background noise before any further data processing is carried out. This practise is known as "band-pass filtering." Passive acoustic filters of higher order have the potential to produce improved roll-offs at low frequencies when utilised as a shield in front of the transducer. This is because electronic filters don't have this capability. This eliminates the requirement for electronic filtering and reduces both the weight and size of the payload that needs to be placed inside the underwater vehicle. This is especially helpful in situations where space is at a premium. In this thesis, higher order (t second-order) passive acoustic notch, high pass, and band-pass denoising filters are designed. Additionally, an acoustic demultiplexer is designed to separate the acoustic signals into various frequency bands suitable for underwater communication and meteorology systems. These two types of systems are discussed in greater detail in this work. Developed specifically for application with these filters On the basis of their spectral absorption characteristics and their capacity to govern the flow of acoustic energy via structurally built composite materials, frequency-selective devices may be separated into two distinct categories. The first of these is the spectral absorption category. In accordance with the manner in which they function, frequency selective components can be divided into two primary categories. Structure-based regulation of frequency response is the superior choice because the design is not reliant on the components that are used in the manufacturing process of the gadget. Additionally incorporated into the design is an adaptability to a broad spectrum of frequencies as well as weather conditions. According to the research that has been done, there are two different approaches that can be taken when putting together structure-based frequency selective devices. The ABG and PC structures, in addition to those based on acoustic metamaterials, serve as the basis for these techniques. Either of these two implementation strategies can be used to create structure-based frequency selective devices (AM). The first group makes use of artificial composite structures that have periodic acoustic impedance fluctuations on the order of wavelength, whereas the second group makes use of locally resonant structures that are produced at periodicities below wavelength. The sections that are to follow will investigate how these frequency selective devices can be implemented, the modelling approaches that are used for them, as well as the benefits and drawbacks that can be gleaned from the research that is currently available, and they will also discuss the methodology that was utilised in this study in an effort to achieve its purpose.

ACOUSTIC FILTERS

Acoustic filters are pieces of equipment that may either allow a specific wavelength or range of wavelengths through or prevent them from doing so. They are capable of acting as amplifiers that are wavelength selective. There are notch filters, which are able to block a particular frequency range, bandpass filters, which are able to transmit a particular frequency range, high-pass filters, which are able to transmit higher frequencies, and low-pass filters, which are able to transmit lower frequencies. All of these filters fall into the category of frequency filters. There are many different kinds of filters, and Figure 1. is a diagrammatic illustration of these filters and the transfer functions that they use. The application of acoustic denoising filters has become widespread in a variety of fields, ranging from applications in defence and other scientific domains that require critically stable vibration isolations to everyday civilian applications, such as mufflers in automobiles, noise filters in industries, and noise filters in household appliances, such as refrigerators. The frequency range of operation and roll-off of these filters are diverse from one another in each of these instances since the filters are customised to match the requirements of each of these applications. On the basis of the underlying operational principle, these filters can be divided into two primary categories: the first category is based on the spectral absorption characteristics of the materials, and the second category is based on structurally engineered composite materials that exert frequency-dependent control over the flow of acoustic energy. The first category is based on the spectral absorption characteristics of the materials, and the second category is based on these characteristics. These two types of filters are collectively referred to as spectrum absorption filters. Over the course of the past decade, researchers working in the fields of AM and ABG have conducted a significant amount of research employing phononic crystals and ABG structures, respectively .

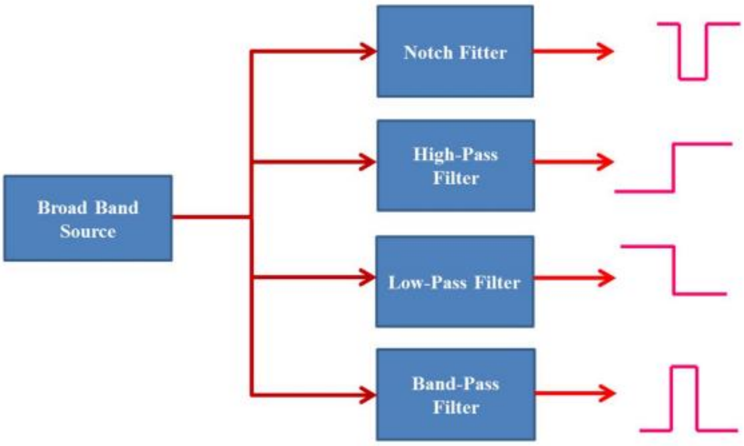

Figure 1. A diagrammatic representation of the numerous varieties of acoustic filters

Related work

Chen, M., et al[3] The utilisation of this superlens makes it much easier to put plans into effect on the battlefield. In addition, due to the fact that it is solid, it is more suited for use in circumstances that involve the presence of water. According to the results of the study, it would appear that this novel design for an acoustic superlens has the potential to open the way for new and beneficial applications of superlenses that are based on metamaterials.

Yang, Xishan, et al.[4] The diffraction restriction imposed by the bulk wave's wavelength in air can be overcome using an acoustic superlens. It is true that subwavelength imaging has a somewhat narrow frequency range. Helmholtz-resonator-based metamaterials have been used to produce an auditory superlens capable of enhancing super-resolution. An experiment is carried out to verify the subwavelength imaging of double slits. Images of these lines can be made visible at frequencies between 560 and 670 Hz. The Fano resonance, which is separate from the Fabry-Pérot resonance, is the underlying process for subwavelength imaging. Helmholtz resonators that are separated by a subwavelength interval have significant coupling, resulting in increased sound transmission over a broad spectrum of frequencies.

Park, Jong Jin, et al.[5] An audio superlensing was manufactured by employing metamaterials with a negative density that were built on two-dimensional membranes. Through the use of two point sources that are kept at a distance equal to 1/17 of a wavelength from one another, it is possible to generate images that have a high level of resolution throughout the metamaterial slab. The subwavelength resolution is a direct result of the surface wave that is generated when negative density is present. For example, it might be put to use in imaging and sensing applications in the field of acoustics.

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Lu, W. T., et al[7] Our research shows that the optical properties of a metamaterial composed of aligned metallic nanowires embedded in a dielectric matrix are highly anisotropic. Using the nanowire axes as reference points, the composite medium shows two surface plasmon resonance (SPR) modes. These resonances allow for broadband all-angle negative refraction and superlens imaging to be accomplished.. An image theory can be applied to superlenses made up of these materials. Gold, silver, or aluminium nanowires implanted in nanoporous templates will be used to create high-performance systems that will work successfully at frequencies ranging from the infrared to the ultraviolet.

Ao, Xianyu, et al[8] It is possible to increase the anisotropy of a two-dimensional acoustic metamaterial by creating it with two axes of rotation that are orthogonal to one another. With the help of this metamaterial's rectangular equal frequency contour, it is possible to generate acoustic hyperlenses, just like the electromagnetic hyperlenses that were previously proven in the optical regime. Imaging is one potential application for a metamaterial that obeys the scalar wave equation.

Grekova, E. F. [9]Point-body motion in linear elastic complex media is described by two generalised vectorial coordinates, and the elastic energy has a term that ties them together. Every problem has an ideal way to solve it. We use modified Lagrange equations to study how this continuum moves. Our work defines a class of media in which the gradient of any of the generalised vector coordinates has no effect on the strain energy. This generalised coordinate is called "Special." Under certain inertial and elastic conditions, the medium acts like a system of independent harmonic oscillators on the partial frequency of the special generalised coordinates. However, under other conditions, there is only the simple solution. For most of the dispersion curves, it has been shown that there is a frequency band gap that exists regardless of the form of the generalised coordinates. In other words, the medium is a single negative acoustic metamaterial within this frequency band. Most dispersion curves have a gap in the frequency band, which shows this. The size of the band gap is limited by the partial frequency of the "special" coordinate. In addition, the dispersion curve for some parameters is going down, which means that the medium is also a double negative acoustic metamaterial in that frequency range.

Proposed methodology

HIGH-PASS AND BAND-PASS ACOUSTIC FILTERS BASED ON ACOUSTIC METAMATERIALS

High-pass and band-pass AM filters are analysed and broken down in depth for the purpose of educating the reader throughout the course of this research. By utilising a high-pass filter, it is possible to get rid of all of the undesirable noise in the infrasound spectrum as well as some of the audible range. This is a feat that has been accomplished before. In any scenario, this objective is attainable. A metamaterial with a negative density will have a negative density at all frequencies below the cut-off frequency if the cut-off frequency is high enough. This holds true even if the frequency at which the cut-off occurs is quite low. It is of the utmost importance that the cut-off frequency be set at a sufficiently high value. Because there is no acoustic velocity in this section of the zone, transmission is not going to be possible in this location. Because of this feature, NDAM's ability[10] to produce high-pass filters by first filtering out low frequencies has been utilised in a wide variety of filtering applications. These applications include: When the modulus and density of a medium, which are the parameters that define the medium's acoustic velocity, are both negative at the same time, the acoustic velocity of the medium is considered to be a real number. This occurs when both the modulus and density of a medium are positive at the same time. This is due to the fact that the modulus as well as the density are the parameters that define the acoustic velocity of the medium. The fact that DNAM has a bandwidth that is only slightly wider than the average allows it to be utilised in the manufacturing of band-pass filters[11]. When it comes to determining how effectively a band-pass filter operates, the negative modulus is the factor that bears the most weight. This is as a result of the fact that negative density can occur across a broad frequency range. You can also make a sandwich by sandwiching a conventional positive zone in between two SNAMs in order to generate a pass band. This is another way to make a sandwich. This is yet another method that can be utilized[12] to produce a pass band.

FILTERING DONE BY COMBINING THE USE OF A HIGH-PASS REGULATION WITH THE APPLICATION OF A FLAT FORMULA The effective density of the composite structure in this NDAM-based filter is less than one, which can be attributed to the fact that the effective density of the composite structure is less than one. This can be attributed to the fact that the subwavelength spacing as well as the tensile stress that is applied to a number of membranes inside of the rigid tube that is filled with fluid results in the effective density of the composite structure being less than one. The type of NDAM that is being addressed in this article is depicted pictorially in Figure 2, which can be found below[13]. In its entirety, the NDAM Schematic Drawing can be seen depicted in Figure 2. It is possible to minimise the overall size of the structure since the individual building components that make up NDAM are smaller than a wavelength. This allows for the structure to be built on a smaller scale. It is possible that the use of these microscopic acoustic filters could be of significant advantage to military communication systems and equipment, particularly those geared to reduce the amount of background noise that is present in restricted locations. AM filters, on the other hand, don't require the signal to be converted from acoustic to electric or electric to acoustic in order for them to be able to filter acoustic signals. AM filters can filter both electric and acoustic signals. This indicates that AM filters might begin filtering acoustic signals as soon as they are added to the system. As a consequence of this innovation, acoustic signals are now capable of being filtered. After that, we will move on to the modelling and building of a high-pass filter[14] that is based on an NDAM. Following that, we will discuss the theoretical underpinnings of the filter. The abbreviation for "nonlinear dynamic analysis method" (NDAM) is "ndam."

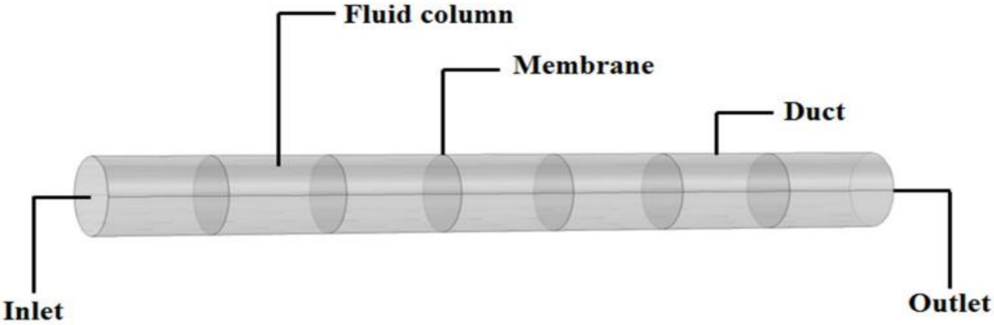

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Figure 2: Schematic representations of NDAM

Each NDAM is built from a series of fluid compartments that are daisy-chained together and are partitioned by membranes in order to maintain their individual identities. Not only will any wave that moves in a longitudinal path across the structure generate oscillations in the fluid columns, but it will also cause oscillations in the membranes of the structure. Within the entirety of the fluid-membrane system, resonance takes place at a particular frequency[15]. This resonance is dipolar in nature, and it helps to contribute to the acoustic structure by bringing about an effective density that is lower than zero. The TLT model is able to offer an adequate justification for the resonance observed in the system.

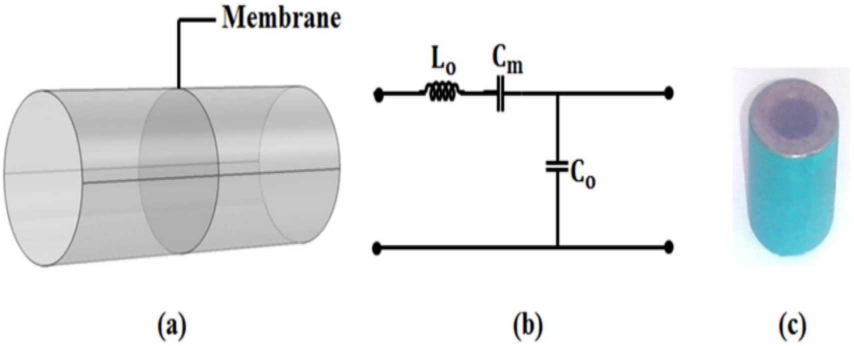

Figure 3 presents an illustration of the electrical equivalent circuit that is present in an NDAM unit cell. (a) a representation of the NDAM unit cell in the form of a schematic, and (b) a representation of the NDAM's electrical equivalent circuit. (c) A sample of an NDAM unit cell that has been made

Figures ad and BT represent, respectively, the inductance and capacitance corresponding to a rigid cylindrical duct, where d is the periodicity at which membranes are distributed, an is the area of cross-section, B is the bulk-modulus of the permeated fluid, = (+ mad) is the average density of the membrane and the loaded permeated fluid[16], is the mass of the membrane, and is the density of the permeated fluid. Both Figure ad and BT, in their Own Right, Represent According to TLT, a capacitor can be created by using a membrane that has been stretched and then placed inside of a duct. If IJ is supposed to stand for the tension of the membrane, then the capacitance that the membrane causes can be expressed as C = a + b. This equation can be written down. It is possible to express the resonance frequency as The fact that the fluid column and membrane together constitute a series inductor-capacitor circuit accounts for the fact that the

$$\omega_c = \frac{1}{\sqrt{L_o C_m}} = \sqrt{\frac{8\pi\tau}{\rho' ad}}$$

Effective medium theory can be utilised to calculate the effective density of this composite metamaterial; the formula for doing so is where is the angular frequency of the acoustic wave. This is one of the many applications that could be made use of effective medium theory. This reality is obscured from view due to the fact that the effective density of the structure diminishes as it moves further away from the resonance frequency of NDAM, which is the point at which it flips from positive to negative[17]. Because of this, the resonance frequency of NDAM is also known as the cut-off frequency. This is because the two frequencies intersect at exactly this point. If the effective bulk-modulus of the structure is equal to the bulk-modulus of the fluid that is being penetrated, then the wave-vector of NDAM can be determined by using the Equation. As a direct result of this, the wave vector can be determined using the following formula:

$$\rho_{\mathrm{eff}} = \rho' \left(1 - \frac{\omega_c^2}{\omega^2}\right)$$

This is due to the fact that effective density is negative below the frequency at which NDAMs cut off, which results in the wave-vector being imaginary. This is because the effective density and cut-off frequency both have a relationship that is inversely proportional to one another. As a consequence of this, the structure is capable of obstructing any acoustic waves that fall inside this frequency range. Estimating the transmission loss in an acoustically[18] opaque environment can be accomplished via TLT through the use of a scattering matrix. The transfer function of an MHR-based four-port acoustic demux using cascaded membrane flexi-walled Helmholtz resonators (MHR) has been modelled by combining two physical systems by using the transmission line equivalents of their unit cells. The results have been confirmed by using full wave analysis. In order to create the MHRs, cascaded Helmholtz resonators were utilised as building blocks. The process of obtaining an expression that describes the transfer functions of each output port has been worked out. It is believed that the stop bands in the throughput port are created by the MHR's reflecting, the negative bulk modulus area, and the fantastic transmission over the membrane. Researchers have discovered that the frequency and bandwidth of stop bands may be altered by modifying the unit-cell periodicity and the membrane tension. This allows for greater control over the characteristics of the stop bands. With the help of this sonic demultiplexer, separate acoustic sounds coming from a variety of bands can be demultiplexed and redirected to a variety of ports.

Acoustic Demultiplexer

At the conclusion of the thesis, a one-of-a-kind acoustic demultiplexer equipped with four ports was demonstrated. This AM-based demultiplexer[19] has a structure that is similar to a ladder, and it uses the metamaterial properties of the material, such as negative density and negative bulk-modulus, as well as the extraordinary propagation of sound waves due to the material's zero effective density, in order to separate various frequency ranges from a broad range composite signal. These properties include negative density and negative bulk-modulus. Additionally, this demultiplexer uses the extraordinary propagation of sound waves due to the material's zero effective This demultiplexer is made up of several fundamental parts, the most important of which are a duct that is loaded with a membrane, a duct that is empty, and narrow tubes, also called necks, that connect the ducts stated in the previous sentence. When waves in different frequency ranges satisfy the various constraints set by the metamaterial, an event known as demultiplexing of the acoustic waves takes place. The structure contains a number of ports that are connected in various ways to the many frequency ranges that have been demultiplexed. The membrane tension, periodicity, the radius of the duct, the density and bulk-modulus of the fluid that is being penetrated, and a variety of other factors are some of the parameters that influence the outcome of frequency demultiplexing[20]. In order to be able to establish the requirements for demultiplexing, a number of expressions have been devised, and numerous theories have been proposed in order to explain those needs. A full-wave analysis that was based on FEM has provided convincing evidence that the hypothesis is accurate.

Conclusion

In order to construct an acoustic superlens out of water, we propose making use of a metamaterial in the shape of a star. The band structure of the metamaterial, as well as the values of its parameters, provide the impression that it possesses double-negative index qualities in the frequency range of 8760–9574 Hz. Within this frequency region, the refractive indices are found to be negative. According to negative refraction and eigenfrequency contours, the structure in the shape of a star has a refractive index that is about equal to one and occurs at 9380 Hz. This illustrates that the lens is able to concentrate sound waves with a spectral response similar to the one being considered here. Because of diffraction, the lens is only capable of resolving an image to 0.39 microns, according to the calculations, which is significantly lower than the resolution that is required for high-definition photography. This super lens has a straightforward design, which makes it much simpler to put into practise. Because it is a solid material, it is better suitable for usage in conditions that involve moisture because of this quality. According to the findings of the research, this novel design for an acoustic superlens has the potential to open the door to new and practical uses of superlenses that are based on metamaterials.

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