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Design of Ultrasonic Receiver using COMSOL

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Abstract

This paper is a study and comparison with design of ultrasonic receiver by using "COMSOL". The device uses piezoelectric materials which is suitable, echo-friendly, should produce a considerable electric potential towards deformation produced by an applied pressure obtained from the transmitter. The design is based on the principle of echo location. The echo location principle is obtained from the obstacle detection nature of the bat. The bat itself acts as transmitter as well as receiver for the detection of the ultrasonic wave for its motion. The piezoelectric material operates on the basis of polarization of the dipoles present in the piezoelectric substances. The device designed here is supposed to deal with the receiver issue along with it the issue of power consumption and environmental safety is taken in to consideration. The ultrasonic devices are normally designed using PZT-5H (Lead zirconate titanate), which contains 60% by weight of lead. Its performance is very good in comparison to other piezoelectric materials but due to environmental issues we opt to use lead free materials like Barium Titanate ($BaTiO_3$) and Lithium niobate ($LiNbO_3$). The various parameters obtained are compared with the parameters of PZT-5H[1].

Keywords

piezoelectric materials, echo Location, polarization

Introduction

Ultrasonic waves are Mechanical waves. Human beings are capable of hearing up to 20 KHz frequency. The range of ultrasonic wave is above 20 KHz i.e. beyond the hearing capacity of human beings. Although several known and unknown sources are capable of transmitting ultrasonic waves, due to lack of appropriate technology we are unable to receive and manipulate the data in a portable manner. Although to some extent radar can do the job, due to lack of its portability and high power consumption its operation gets limited. The paper deals with the design of portable echo friendly receiver using different lead free piezoelectric materials like Barium Titanate ($BaTiO_3$) and Lithium Niobate ($LiNbO_3$). They all are simulated under a common environment and the results are analysed.

The astronauts use high frequency signals to notify the presence of objects in the space. The speeds of ultrasonic waves depend upon the medium of propagation. The high frequency signals present in the space deflected from different size objects, from the strength of the wave the astronaut gets idea about the size and location extraterrestrial bodies present in space. There are two types of ultrasonic waves present in nature, first is bulk or fundamental waves: it propagates inside the objects; second is guided waves: that propagates near the surface or along the interface of the objects. [10]

In nature bats uses the principle of echo-location, the bat itself act as a transmitter as well as receiver for this purpose.[3]

"Honeywell" has also designed ultrasonic sensor which can be used as a receiver to some extents, but it has little bit high power consumption. The products are designed under 943-serise. The product is also not echo-friendly, may causes personal injuries. [12]

I. Motivation

The concept of designing the ultrasonic receiver is obtained from the echo location principle of the bat. The bat is unable to visualize the obstacle or objects present in its flight path so it emits high frequency sound waves from its voice box or larynx the waves moves faster than the speed of the bat, gets reflected

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and received by the organ near the ear of the bat, thus gets the alert with quite a safe distance, hence able to navigate properly. [3] Though this work can be solved to some extent but due to lack of portability and high power consumption it cannot be used everywhere.

II. Ultrasonic Receiver :

The ultrasonic wave or ultrasonic waves are the terms used to describe elastic waves with frequency greater than 20,000Hz normally exist in solid, liquid and gas.

The transducer is a device which converts one form of energy into the corresponding electrical energy. Ultrasonic receiver is a part of the ultrasonic communication system. The ultrasonic transmitter is made by a suitable echo friendly piezoelectric material having a better electrical characteristic in response to the deformation introduces by the pressure of the ultrasonic waves. [9, 3] Due to the deformation of the piezoelectric substance the arrangement of the dipoles changes, the relative separation of the partial charges of the dipoles one surface of the piezoelectric. Substance act as positive side and the opposite side act as negative side so a potential difference is created. The ultrasonic waves coming from the transmitter propagates through the air medium and when the transmitted high frequency ultrasonic waves strikes the surface of the piezo -electric material of the receiver, there it creates a deformation that gives rise to electric potential.

The velocity of the ultrasonic wave depends upon the temperature according to the following relation

C=331.5+0.607**T** m/s..............(1)

T=temp in Celsius

The strength of the ultrasonic waves attenuates proportionally with distance due to the diffusion losses in medium due to diffraction and absorption losses [13,2].

For a particular temperature with rise in frequency the attenuation increases hence range decreases.

The typical limit of the piezoelectric material is 500volt/mm can sustain maximum mechanical stress. The sound pressure level (S.P.L) can be determined by the following formula,

$$s.p.l = 20\log\frac{p}{p_o}dB.........(2)$$

P=sound pressure level

Po=reference pressure level

The distance of the object can be determined by

D=Ct/2 m..........................(3)

C=velocity of sound

III. Design Of Receiver:

Design of ultrasonic receiver using the different piezoelectric materials. Taking care of several characteristics of the materials the design is tested on the several piezoelectric materials.

The design deals with the making of the device using COMSOL Multi-Physics 4.3, this tool is versatile software that is capable of designing various micro and macro level structural and acoustic designs and simulate them in order to obtain the various parameters.

The specified dimension of the transmitter is 100 μm in width 20 μm in height. The air is taken as medium of propagation having dimension 100 μm in width and 200 μm in length. The dimension of the receiver is 100 μm in width and 20 μm in thickness.

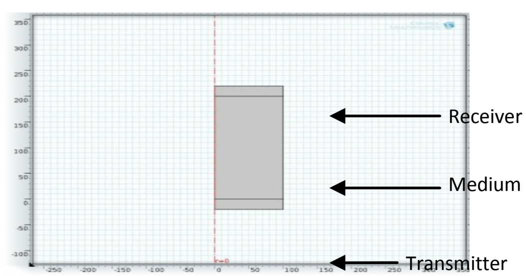

Fig-1(combined structure of transmitter and receiver)

ISSN 2348 - 7968

The structure designed is 2-D asymmetric in nature, the 2-D asymmetry structure means the structure is designed on X-Y plane and it can freely rotate about Z-axis as given below

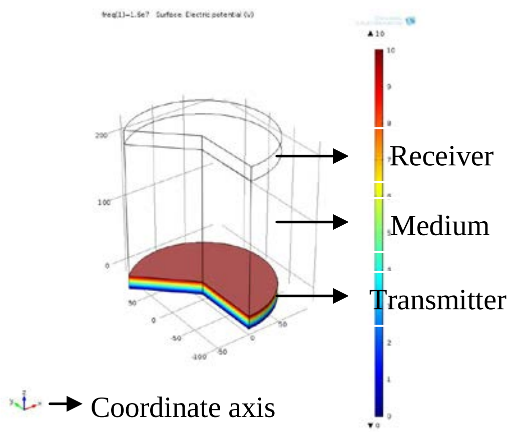

Fig-2(2-D asymmetry structure)

The transmitter as shown in the above fig-2 is given a 10 volt potential and simulated at 16 MHz frequency.

The Barium Titanate is a large transparent crystal and insoluble in water. The density of Barium Titanate is 6.02gm/cm^3,it melts at 1625^{0}C the band gap energy of it is 3.2eV.The Lithium Niobate is a colourless solid having density 4.65gm/cm^3,its melts at 1257^{0}C Its band gap energy is 4eV which is more than Barium titanate The air is used as medium of propagation its dielectric strength at 1atm which remain fixed up to 100atm.The dielectric constant of it is 1.00059 at 1 atm. And 1.0548 at 100atm.The permittivity of air is8.854*10^{-12}F/m[2].

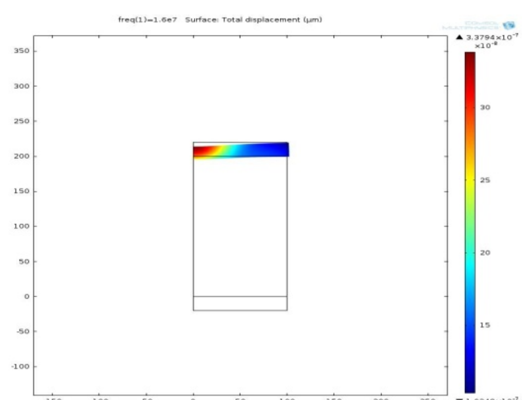

Fig-3 (deformation of Barium Titanate receiver)

The displacement occurs in the receiver material due to the impact of the mechanical wave generated at transmitter. The above fig-3 shows the displacement due the acoustic pressure its value is3.3794*10^{-7}.Micro meter for Barium Titanate. By the acoustic pressure the material deforms at contact boundary. The dipoles present in the Barium Titanate start to response to the polarization effect of the acoustic pressure, when the pressure value increases the upon the bottom boundary of the receiver the material shows its elastic behavior due to the flexibility of its dipoles inside the crystal lattice. The material try to expand in the opposite direction of the applied force, the degree of expansion shows the degree of polarization effect on the dipoles [6].

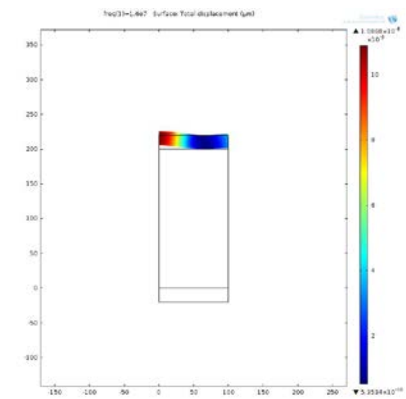

Fig-4(deformation of Lithium Niobate receiver)

The Lithium Niobate produces near about less displacement than Barium Titanate, its value is 1.0868*10^{-8}micro meter.

IV. Potential In 3-D Mode :

Due to relative separation of the dipole moments one side means one boundary of crystal act as partial or relative positive and the other side act as relative negative potential. The negative potential side is assumed as ground or fixed boundary. The potential varies linearly.

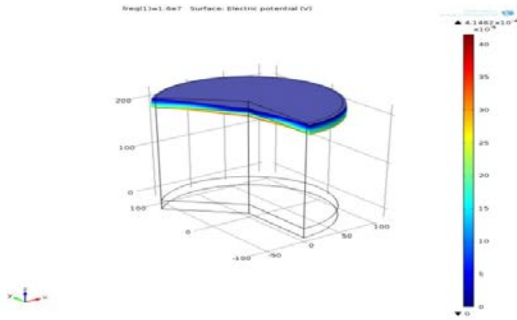

Fig-5 (potential variation of Barium Titanate)

The relative potential produces is4.1462*10^{-4} V

The potential variation of the receiver using Lithium Niobate is shown below.

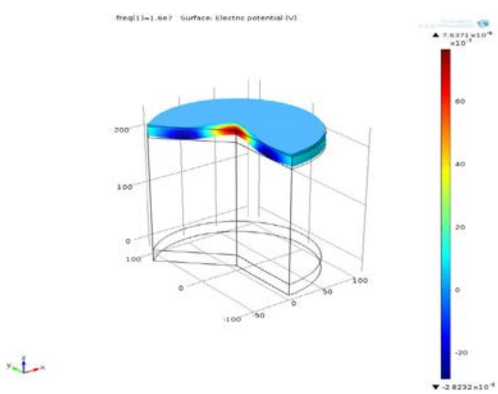

Fig-6 (potential variation of Lithium Niobate)

The highest range of potential is found to be 7.6371.*$10^{-6}V$.

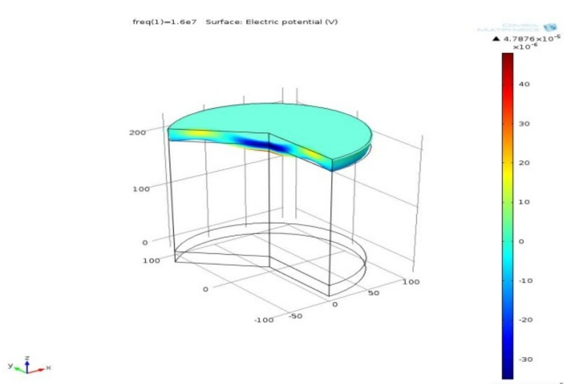

Fig-7 (potential variation of Lead zirconate Titanate)

The highest range of potential is found to be 4.7876*$10^{-5}V$

V.Acoustic pressure plots in the air medium :

Due to the activation of the transmitter it transmits mechanical waves into the air according the its elasticity of material the peak of pressure varies.It also depend upon the frequency applied for simulation.

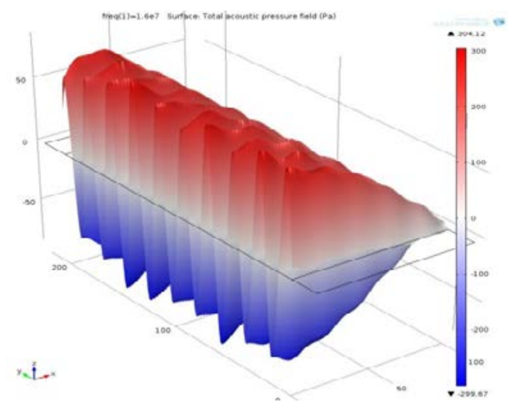

Fig-8(transmitted wave in air for Barium Titanate)

The peak value of the acoustic pressure for Barium Titanate is near about 304.12 Pascal as shown in fig-8.

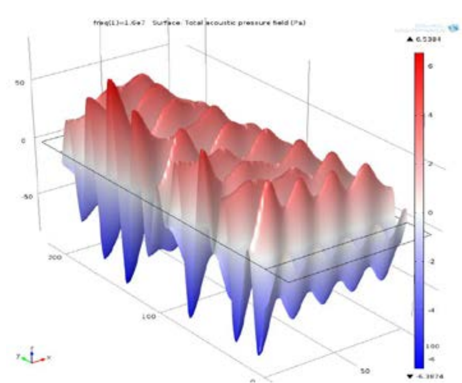

Fig-9(transmitted wave in air for Lithium Niobate)

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The peak point pressure for Lithium niobate is6.53.84pa.

VI.Stress Plots:

The acoustic pressure which exert pressure on the receiver also generate a pressure on the material which actually causes the deformation leads to generation of the potential. The stress created in Barium Titanate is 1101.7 N/m^2 as plotted below(fig-10)

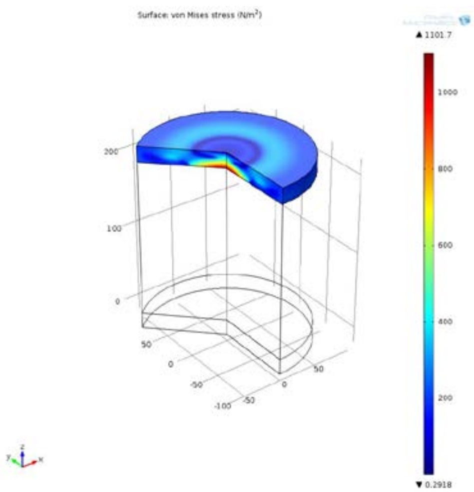

Fig-10(stress plot in 3-D for Barium Titanate)

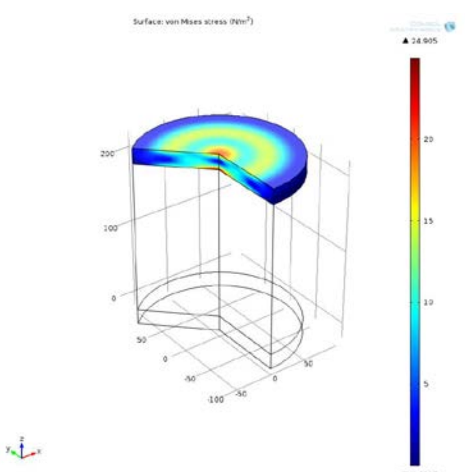

Fig-11(stress plot in 3-D for Lithium Niobate)

The Lithium Niobate produces low pressure in order of 24.905 N/m^2.

VII. Result Analysis:

The pressure generated by the transmitted wave on the receiver produces a recognizable level. The below tabulation shows the different parameter comparison.

Table-1

PIEZO ELECTRIC MATERIALS	ACOUSTICPRESSURE(Pa)	DEFORMATION (μm)	Potential(v)
Barium Titanate	304.12	$3.3794*10^{-7}$	$4.1462*10^{-4}$
Lithium Niobate	6.5384	$1.0868*10^{-8}$	$7.6371*10^{-6}$

From the above tabulation we can analyse that although Lead Zirconate Titanate produces more acoustic pressure for same applied potential than the Barium Titanate ,Barium Titanate produces relatively more potential than Lead Zirconate Titanate.

VIII.Conclusion:

By using COMSOL Multiphysics we designed the ultrasonic receiver and the combined module successfully. From the analysis of the result through the different characteristic curves and 3D plots. The Barium Titanate crystal provided us a better characteristic and suitable combined module .On simulation it also produces better acoustic pressure and potential.

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