Design and Simulation of MEMS Based Directional Microphone for Gun Firing Detection

Namitha J,
Student, Dept. of ECE,
VVIET, Mysuru

Bindu A Thomas
HOD, Dept. of ECE
VVIET, Mysuru

Abstract- **Direction detection of gun firing can provide the security in the highly secured area in various circumstances such as defense area. The ability to detect gunshots can provide someone with valuable information in various circumstances. For the military and public servants detecting gunshots can help in saving lives and potentially target offenders. Most current methods for gunshot detection require expensive devices to build or developed. To overcome this problem sensors are developed by using MEMS technology due to smaller in size and effectiveness that reduces the overall cost of detection system. MEMS directional microphone can be used to determine the direction of the incoming sound wave generated by gun firing. Thus designing and fabricating the directional microphone for detection of gun firing direction using MEMS technology provides several advantages that includes small in size, low cost, very high sensitivity etc. A microelectromechanical direction-finding sensor has been developed based on the mechanically coupled ears of the Ormia Ochracea fly, which has a partition of only 520µm between its ears however has the capacity accomplish directional determination equivalent to the human's capacity. The fly has the huge capability of recognizing the change in the angle of incidence of sound that is as less as 2°.**

Keywords – MEMS, Directional Microphone, Comsol Multiphysics.

I. INTRODUCTION

Sniper localization system has gained popularity in recent years in the field of law enforcement, civil protection, and military application. Locating enemy snipers using traditional methods based on human senses is extremely wasteful and might require more than one attempt. Thus an acoustical detection system that can detect the gunshot direction and classify specific firearms and localize the snipers is of great importance. There are different types of sensing mechanisms that are utilized to sense incoming acoustic signals, the most common techniques are Capacitive, Piezoresistive and Piezoelectric. A MEMS directional microphone is a device which has the knowledge to sense the direction of the acoustic pressure falling on its diaphragm.

A MEMS directional microphone structure is inspired by a fly Oramia Ocharea. The fly has the huge capability of recognizing the change in the angle of incidence of sound that is as less as 2°. As per the requirement for small devices, the microphones are essential to be small with high performance. The sound direction is firmed based on the time variance of arrival of the signal between microphone arrays. Since characteristically directional microphone is a single device accomplished of determining the sound directionality its desirable than the microphone arrays. Aim of this project is to design and simulation of MEMS directional microphone for direction detection of incoming sound wave generated by gun firing using Comsol Multiphysics. The MEMS directional microphone is designed for detecting the direction of the gun firing which has a spectral content around 400 – 2500Hz on the application of pressure in the range of 1m-10m pa and the distance is covered up to a range of 20-400m..

II. LITERATURE SURVEY

author designed a direction finding using multiple MEMS acoustic sensor. A MEMS direction finding sensor structure is inspired by a fly Oramia Ocharea. The fly has the huge capability of recognizing the change in the angle of incidence of sound that is as less as 2°. In previous studies, sensor has left-right ambiguity problem. To overcome that drawback, a dual sensor are used in this paper. Two sensors are co-located in close proximity to each other, such that amplitude of sound pressure level is nearly same at the both sensors. This study eliminated ambiguous angles and the requirement for a sound pressure level.

[2] Author in [2], have designed a Gunshot Detection System for JTRS Radios. Finding the shooter location is mainly depends on muzzle blast and shock wave coming from the gun firing. The system is designed for direction detection of gunshot is using JTRS radio. Each radio act as a sensor hub. The tests were conducted at a local shooting range. Field trial setup comprises of eight wireless microphone and laptops were set at different areas all through the shooting range. The GPS data was averaged to approximate the military GPS accuracy. The gunshot detection algorithm detected 90% of shots present. 10% of shots distinguished were false positive.

Author[3] designed an acoustic signature of small fire arms for gunshot localization. For detecting and localizing the gunshot, an array of microphones is connected to data acquisition and the processing unit. The acoustics signals are generated from a gunshot. These acoustics signals results in muzzle blast and shock wave. The range of the shooter is determined by using muzzle blast and shock wave and the direction of the shooter is depend on the muzzle blast but not on the shock wave. Field trials were conducted for different distance between sensor array and firing source and for different calibre weapons. The results imply that the gunshot localization parameters could be accurately measured using the system.

Author[4] designed a Shooter Localization in Wireless Microphone Networks. To increase the security level, wireless microphone based shooter localization system is designed. When a shot is fired from a small arm, two distinct acoustic waves are generated: the muzzle blast (MB) and the shock wave (SW).Both the acoustic wave (MB) from the gunfire and the ballistic shock wave (SW) from the projectile can be recognized by the microphones and considered as estimations. The arrival time of muzzle blast in cellular phone network gives the standard sensor network problem and the accuracy of the localization was good..

Author[5]designed an Acoustical Characterization of Gunshots. Assessing then evaluating acoustic firing detection systems requires a thorough comprehension of the characteristics of gunfire sounds along with the significance of sound wave reflection, absorption, diffraction on or after the ground, buildings, also near objects. There are primary attributes that characterize gunfire and hence enable the detection and location of gunfire and similar weapon discharges.

Author[6] designed an Automatic Gun Targeting System. To increase the security level, microcontroller based automatic gun targeting system is introduced. The developed system is based on the PIR sensing. The present system is able to detect the PIR radiation in the range of border and automatically target the position. Main function of PIR sensor is to senses the temperature difference and the signals are coded with the help of microcontroller and transmitted toward the receiver. The signal from PIR sensor is provided to microcontroller, it generates the code and the code is transmitted to the RF receiver with the help of RF transmitter. This system reduces the efforts of soldier in border security. This system is further implemented by using Bluetooth technology and face recognition system.

III. DESIGN METHODOLOGY

The MEMS directional acoustic sensor is designed for detecting the direction of the rifle firing which has a spectral content around 500 – 5000Hz (peak 1000 -2500 Hz). The designed MEMS acoustic sensor has two membranes which are coupled by a hinge to resonate at a particular frequency. It uses capacitive sensing mechanisms, thus structure includes comb drives as sensing element. COMSOL Multi physics and Coventor Ware tools are used to design a MEMS microphone.

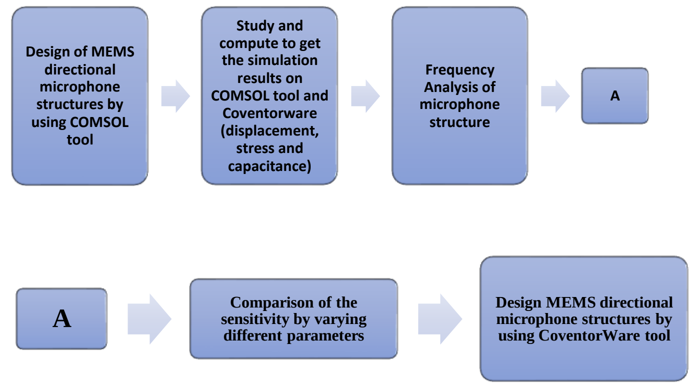


Fig 1: Architecture for designing a MEMS directional microphone.

Figure 1 shows architecture for designing a MEMS directional microphone. MEMS directional microphone structures were designed by using COMSOL Multi physics using comb drive structure. Compute the designed structures to get results like capacitance, stress and displacement on COMSOL Multi physics. At last frequency analysis were improved the situation every single composed model and think about consequence of all models like displacement, stress and make design structure by utilizing CoventorWare for the model which gives best outcome.

A. *Design of different directional microphone structure using COMSOL Multiphysics*

The designed MEMS acoustic sensor has two membranes which are coupled by a hinge to resonate at a particular frequency. It uses capacitive sensing mechanisms, thus structure includes comb drives as sensing element. The structure is designed using COMSOL Multi physics.

Table 1: Design specification of Directional microphone

Dimensions	**value**	**unit**
Wings width	2000	µm
Wings height	2000	µm
Coupling width	1000	µm
Coupling height	100	µm
Comb width	500	µm
Comb height	50	µm
Thickness	10	µm
Pressure	1	m pa

The specifications for the sensor are shown in Table 1. The designed MEMS acoustic sensor has two membranes which are coupled by a hinge to resonate at a particular frequency. The sensor two diaphragm dimension is 2000*2000 µm and a thickness of 10 µm. The material used for designing the sensor is silicon. The comb fingers width and height 500*50 µm and the distance between the fingers is 50 µm. It uses capacitive sensing mechanisms, thus structure includes comb drives as sensing element. Sensors use capacitive comb fingers to produce an electrical output proportional to the wing displacement. The MEMS directional microphone structure is shown in the Figure 2.

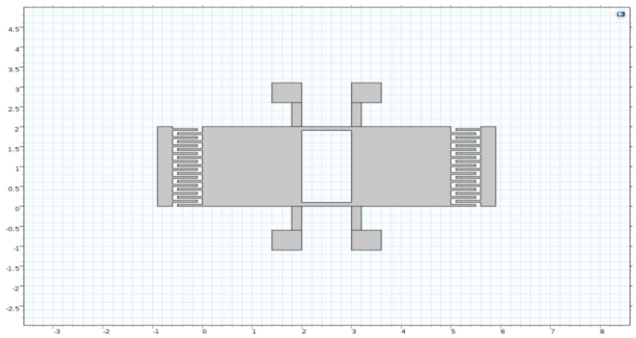


Fig 2: MEMS microphone Structure

B. *Design of directional microphone structure using CoventorWare*

A directional sound sensor is made-up using micro-electromechanical system (MEMS) technology based on the principle of ormia ochracea fly's aural organ. The fly uses attached bars hinged at the centre to achieve the directional sound sensing by monitoring the variance in vibration amplitude between them. The MEMS sensor design engaged is designed using the SoiMUMPs process. The layout structure of a comb drive is shown in the figure 4.6. The comb drive structure Comb-drives are made of two combs, a movable one and a fixed one. Comb drive diaphragm having a dimension of 2000x2000 µm2 and a finger dimension is 500x50 µm2. The distance between the comb fingers is 200 µm.

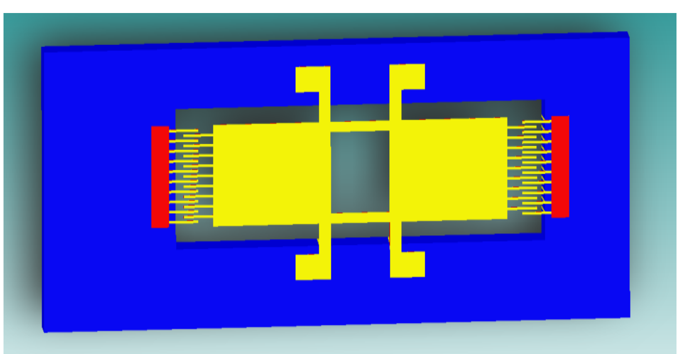


Fig 3: 3D structure of comb drive

IV. DESIGN CALCULATIONS

Electrostatic comb drives are actuators where two inter digitated comb structures can be moved together or apart by applying voltage to either of the two comb electrodes.

1. Capacitance for a single finger is given by the Equation 1

$$C = \left[\frac{(\varepsilon * \epsilon * l * t)}{d}\right] N \text{.................Equation 1}$$

Where, ε is absolute permittivity,ϵ is relative permittivity, L is common length, t is thickness of the finger, d is common area between the plates, N is the number of comb fingers.

2. Wing displacement is given in the Equation 2

$$D = \frac{0.00151 * P * l^2 (1 - Nu^2)}{E * T^3} \text{...............Equation 2}$$

Where, E is Young's Modulus, Nu is poisonous Ratio, ρ is density, l is width of the square diaphragm, T is material thickness, P is Pressure, d is distance between the fingers.

3. Eigen frequency of the structure is given in the Equation 3

$$f = \pi \left[\frac{0.1015}{l}\right]^2 \sqrt{\frac{(E * T)}{(12 * \rho (1 - Nu^2))}} \text{.............Equation 3}$$

Where, E is Young's Modulus, Nu is poisonous Ratio, ρ is density, l is width of the square diaphragm, T is material thickness, P is Pressure, d is distance between the fingers.

4. Stress is the ratio of external load to the cross sectional area. The stress is given in the Equation 4

$$S = 0.03 * P \left[\frac{L}{T}\right]^3 \text{........................Equation 4}$$

Where, L is width of the square diaphragm, T is material thickness, P is Pressure.

V. SIMULATION RESULT

The comb drive structure of MEMS microphone was designed and simulated using Comsol Multiphysics. The total displacement of the structure on the application of pressure is shown in Figure 4.

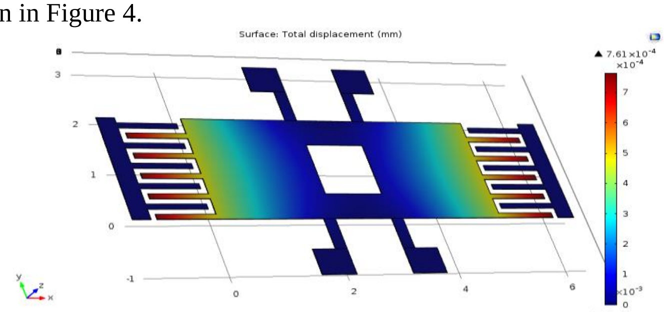


Fig 4: Representation of total displacement

On the application of 1m pa pressure on the sensor diaphragms the total displacement obtained 0.33um and the total stress of the structure is shown in the Figure 5.

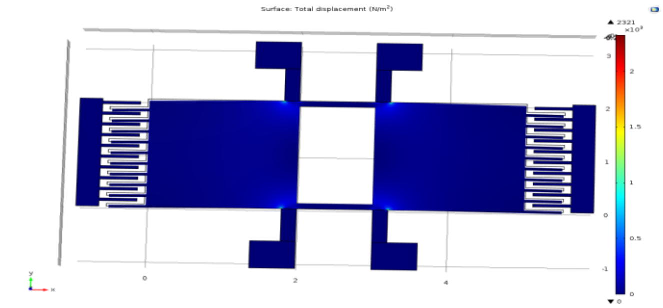


Fig 5: Representation of stress

On the application of 1mpa pressure on the sensor diaphragms the maximum stress obtained is 2321N/m2 and capacitance of the structure is shown in the Figure 6.

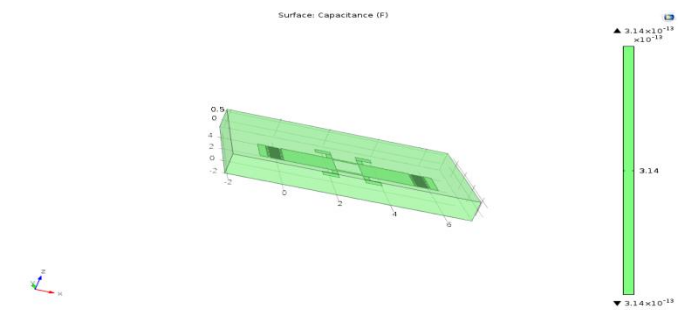


Fig 6: Representation of total capacitance

The total capacitance obtained is 0.314pF on the application of 1m pa and the frequency response of the sensor replicates it as shown in Figure 7. The peak is obtained at 2459 Hz.

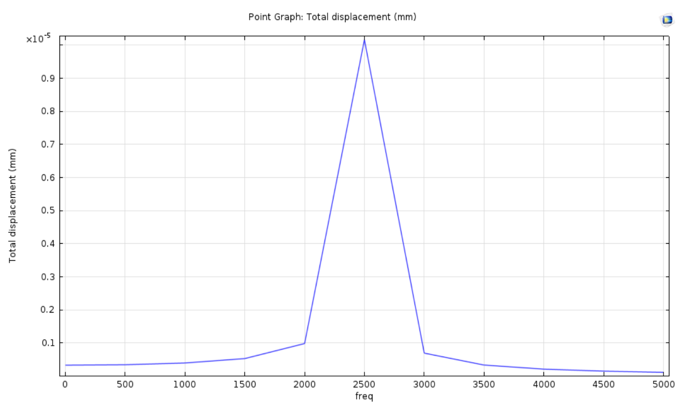


Fig 7: Representation of Frequency

The comb drive structures of MEMS microphone were simulated using Coventorware. Figure 8 gives a maximum displacement of 0.28µm when 1m Pascal pressure is applied on the structure.

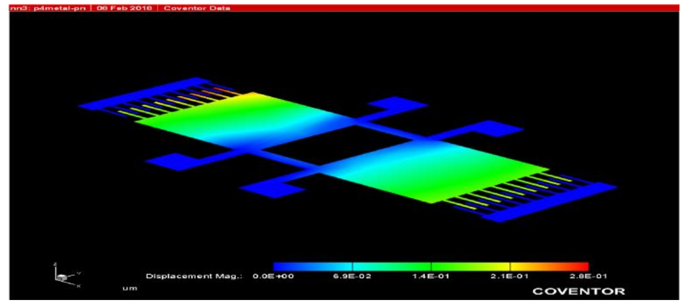


Fig 8: simulation result(displacement)

Figure 9 gives a frequency response in rocking mode of 2629.99 Hz when 1m Pascal pressure is applied on the structure.

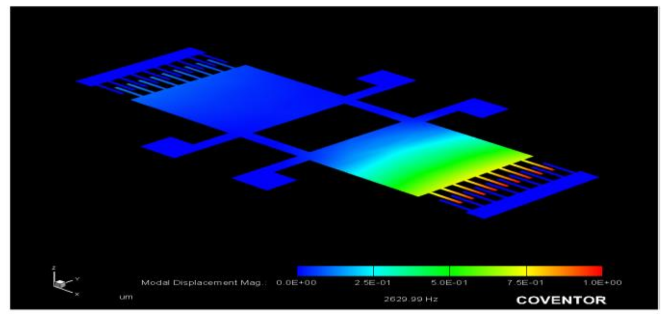


Fig 9: simulation result(frequency response)

Figure 10 gives a capacitance of 0.2pF when 1m Pascal pressure is applied on the structure. Table 2 gives the capacitance values of the structure when the pressure is applied on the structure.

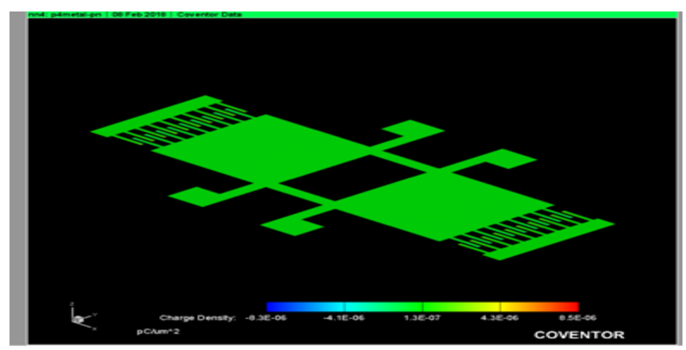
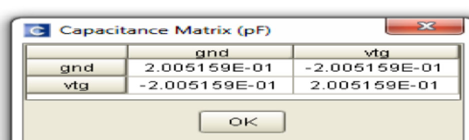


Fig 10: simulation result(capacitance)

Table 2: Capacitance values


Capacitance Matrix (pF)

	gnd	vtg
gnd	2.005159E-01	-2.005159E-01
vtg	-2.005159E-01	2.005159E-01

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Table 3 gives a comparison of the structures that have been simulated in the paper. The sensitivity of the microphone is the difference in the capacitance between the two wing structures of the directional microphone on applying directional pressure. In this analysis, the theoretical value of frequency, displacement and capacitance were matched to practical value.

Table 3: Comparison of practical and theoretical result

Parameters	Comsol	Conventorware	Theoretical
Frequency(Hz)	2459	2629.99	2102.4
Displacement(um)	0.33	0.28	0.378
Capacitance(pF)	0.314	0.2	0.176
Stress(N/m^2)	2321	6000	3750

VI. CONCLUSION

In this work that has been carried out have designed and simulated structures of the MEMS directional microphone. A MEMS based directional microphone was designed using COMSOL Multiphysics and simulated using CoventorWare Turbo. The Directional microphone is biologically inspired from the fly's auditory organ structure of the Ormia Ochracea. The directional microphone structure is designed based on a comb drive capacitive sensing mechanism that can be fabricated using SoiMUMPs process. With the analysis of the results obtained and from the comparison table 5.4 we can conclude that the proposed model have consistence working and it has more advantages when compared to existing system. Thus depending on the application of the directional microphone and based on the requirement of Frequency responses, Capacitor and Displacement the directional microphone can be utilized.

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