Theoratical, Simulation and Experimental Analysis of Sound Frequency and Sound Pressure Level of Different Air Horn Amplifier

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Abstract— In this paper attempt is made to find out approximate value of sound frequency using theoretical and experimental investigations and sound pressure level using simulation and experimental investigations for different horn amplifier length. Theoretical study of sound frequency is done using mathematical formulation and simulation investigation is done using FEA software while experimental investigation is conducted in an open environment using LabVIEW and Data acquisition system. Initially sound frequency of different horn amplifier is found out mathematically taking into consideration length, throat and mouth diameter of horn amplifier. Secondly FEA simulation investigation is carried out using geometry of horn amplifier, acceleration of diaphragm and input air pressure to find out sound pressure level for input air pressure of 1, 1.5 and 2 bar. Finally approximate experiments are carried out to find out sound frequency and sound pressure level for different horn amplifier length for different input pressure and at different distance. The experimental prediction of sound frequency is compared with theoretical analysis while simulation prediction of sound pressure level is compared against the experimental results obtained using LabVIEW and Data acquisition. Reasonable agreement was obtained. It is seen from the results that higher the input air pressure higher will be the sound pressure level and sound frequency of horn amplifier is independent of input air pressure.

Keywords—Sound waves, Horn Amplifier, Sound frequency, Sound pressure level.

I. INTRODUCTION

A. Sound Wave

Sound is an alteration in pressure, particle displacement or particle velocity propagated in an elastic material or the superposition of such propagated alterations. Sound is also the sensation produced through the ear by the alterations described above. Sound is produced when air is set into vibration by any means whatsoever, but sound is usually produced by some vibrating object which is in contact with the air. [15]

If a light piston several inches in diameter, surrounded by a suitable baffle board several feet across, is set in rapid oscillating motion (vibration) by some external means, sound is produced (Figure 1).
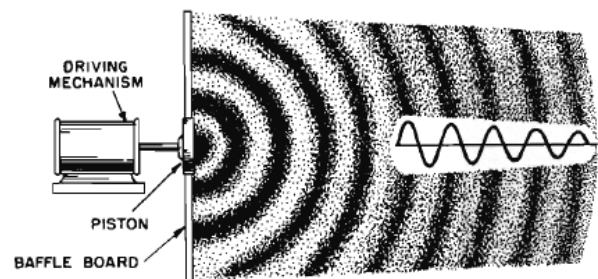

Fig. 1. Production of sound waves by a vibrating piston [15]

The air in front of the piston is compressed when it is driven forward, and the surrounding air expands to fill up the space left by the retreating piston when it is drawn back. Thus we have a series of compressions and rarefactions (expansions) of the air as the piston is driven back and forth. Due to the elasticity of air these areas of compression and rarefaction do not remain stationary but move outward in all directions. If a pressure gage were set up at a fixed point and the variation in pressure noted, it would be found that the pressure varies in regular intervals and in equal amounts above and below the average atmospheric pressure. The actual variations could not be seen because of the high rate at which they occur. Suppose that the instantaneous pressure, along a line in the direction of sound propagation, is measured and plotted with the ordinates representing the pressure; the result would be a wavy line as shown in Figure 1. The points above the straight line represent positive pressures (compressions, condensations); the points below represent negative pressures (expansions, rarefactions) with respect to the normal atmospheric pressure represented by the straight line.

B. Basic acoustical parameters

Analysis of sound and acoustics plays a role in such engineering tasks as product design, production test, machine performance, and process control. In order to perform analysis of sound and acoustics, we should know the parameters and process for acoustical measurement. In general, there are many physical parameters that should be measured in acoustical measurement such as sound pressure, sound intensity, sound power and others. The most common acoustical measurement parameters are as follows[8]

Sound pressure (acoustic pressure) P

Sound pressure is the local pressure deviation from the ambient atmospheric pressure caused by a sound wave. The value of the rapid variation in air pressure due to a sound wave, measured in Pascal. Instantaneous sound pressure is the peak value of air pressure and its value reflects the intensity of sound. Usually, sound pressure is the effective sound pressure for short. Effective sound pressure is the RMS value of the instantaneous sound pressure taken at a point over a period of time as:

$$P = \sqrt{\frac{1}{T}\int_0^T P^2(t)\,dt} \qquad\qquad 1$$

Where P(t) is instantaneous sound pressure, T is the time interval averaging.

Sound Pressure Level LP

Sound pressure level LP is a logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB). For sound in air, it is customary to use the value 2×10^{-5} Pa .

$$LP = 10 \log \frac{P^2}{P_{ref}^2} \qquad\qquad 2$$
$$= 20 \log \frac{P}{P_{ref}} \qquad\qquad 3$$

Where LP is sound pressure level (dB), Pref is the reference sound pressure (2×10^{-5} Pa), P is effective sound pressure [9].

C. *Horn Amplifier Physics*

Figure 2 shows the minimum geometry required to define an exponential horn. The area at the throat S0, the area at the mouth SL, and the length L are used to calculate the flare constant m of the exponential horn. And also the cutoff frequency of sound waves.
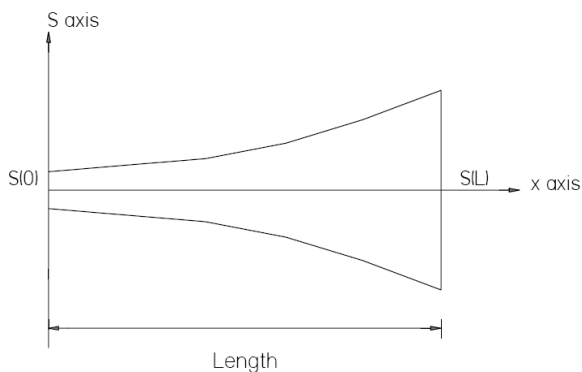

Fig. 2. Exponential Horn Geometry [22]

The exponential horn geometry is described by the following expression.

$$S(x) = S0\, e^{(mx)} \qquad\qquad 4$$

At x = 0 and x = L

$$S(0) = S0$$
$$S(L) = S_0\, e^{(mL)} \qquad\qquad 5$$
$$S(L) = SL$$

From equation 3.2, flare constant m can be derived

$$m = \frac{\ln(\frac{SL}{SO})}{L} \qquad\qquad 6$$

Where,

m = Flare Constant
SL = Area of mouth
SO = Area of throat
L = Length of Horn amplifier

Classical exponential horn wave equation that can be found in most acoustics texts.

c2

$$\left(\left(\frac{\partial}{\partial x}\left(\frac{\partial}{\partial x}\xi(x,t)\right)\right) + m\left(\frac{\partial}{\partial x}\xi(x,t)\right)\right) = \frac{\partial}{\partial t}\left(\frac{\partial}{\partial t}\xi(x,t)\right) \qquad\qquad 7$$

$$f_n = \frac{mc}{4\pi} \qquad\qquad 8$$

Where,

f_n = Frequency in Hz

c = Speed of sound in m/s

$$SL = \frac{(\frac{c}{2fn})^2}{\pi} \qquad\qquad 9$$

From Equation 8, the lower cut-off frequency of an exponential horn can be calculated given a flare constant m. When designing a horn the required flare constant m will be calculated using equation 6, and measuring different dimensions of Horn amplifier.

Similarly mouth diameter SL can be calculated using equation 9, when horn is to be designed for required frequency.

II.   DESIGN OF AN EXPONENTIAL HORN AMPLIFIER FOR DEFINITE FREQUENCY

Assuming that the desired lower cut-off frequency f_n of an exponential horn is 100 Hz, an infinite number of horn geometries can be specified.

$$m = \frac{(4\pi fn)}{c} \qquad\qquad 10$$

$$m = \frac{4\pi\, 60\ Hz}{344\ m/sec}$$

m = 2.19 m-1 = 0.00219 mm

$$SL = \left(\frac{c}{2fn}\right)^2 \qquad\qquad 11$$

$$SL = \left(\frac{344}{2 \times 100}\right)^2$$

SL = 0.942 m^2

III. THEORETICAL PREDICTION OF SOUND FREQUENCY OF AVAILABLE HORN FLARES

The mouth diameter of the horn plays a major role in determining the frequency characteristics. To study calculation of sound wave frequency of sound waves, three acoustic horns of 250 mm, 165 mm and 120 mm of length and same throat and mouth diameter are considered. Following is the table, which shows the different parameters of different horn amplifier.

TABLE I.   PARAMETERS OF HORN AMPLIFIERS A, B AND C

Horn	Throat Diameter (mm)	Mouth Diameter (mm)	Length (mm)
Type A	10	57	250
Type B	10	57	165
Type C	10	57	120

To check the cut off frequency of above horn amplifier, following steps are carried out.

For Type A

We found dimensions as follows,
Mouth Diameter   = 57 mm
Throat Diameter   = 10 mm
Length   = 250 mm
Following are the useful formulas for calculating horn dimensions.

$$fn = \frac{m\,c}{4\,\pi}$$

Where,
c = Speed of Sound in Air at 20°C = 340 m/sec
fn = Frequency in Hz

$$\text{Area of Mouth} = \frac{\left(\frac{c}{2fc}\right)}{\pi}$$

$$\text{Flare Constant } m = \frac{\ln\frac{57}{10^3}}{250} = 0.01392$$

$$fn = \frac{0.01392 \cdot 340 \cdot 1000}{4\,\pi}$$

Repeating same procedure fn for Type B and Type C Horn can be calculated.

TABLE II.   THEORETICAL PREDICTION OF SOUND FREQUENCY OF HORN FLARE A,B AND C

Sr No.	Horn	Frequency Hz
1	Type A	381.25 Hz
2	Type B	577.90 Hz
3	Type C	794.54 Hz

IV. SIMULATION ANALYSIS

A. Methodology of simulation study

Methodology for simulation of acoustic amplifier is having three simple steps.

1- Model
2- Boundary conditions
3- Study Results

B. Model

To do computer simulation study of any product, or component it is foremost thing, as our limit is upto 2D simulation, 2D model is built in model environment of FEA software.

To do computer simulation of available horn amplifier, 2D model is built of respective size i.e. Mouth and Throat Diameter, and horn amplifier length.

Figure 3 shows the equivalent geometry of horn amplifier with sound generator and area of sound propagation.
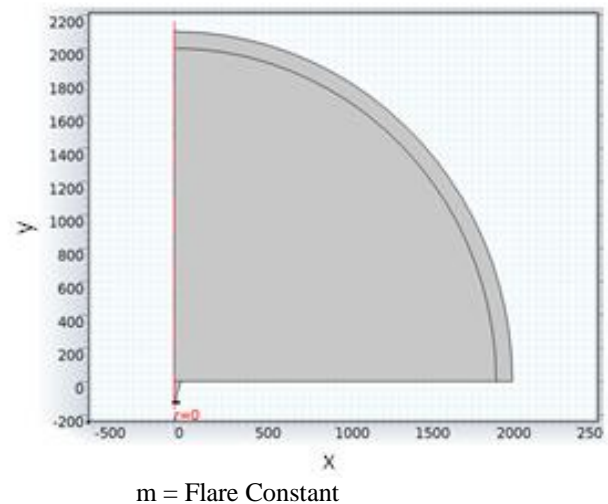

m = Flare Constant

Fig. 3.   Horn amplifier of length 120 mm with sound generator and area of sound propagation

Figure 3 shows the model made in 2D, and shows the horn amplifier, with sound generator, and also open environment, which will be helpful in taking reading (sound pressure level) at particular location. As traveling of sound is purely in air, so during modeling air is used as material for simulation.

C. Boundary Condition

$$fn = 381.25 \text{ Hz}$$

After making the model of required size, next important step is to properly select the boundary condition to get the appropriate solution of the problem. For simulation purpose area of 2m radius is considered.
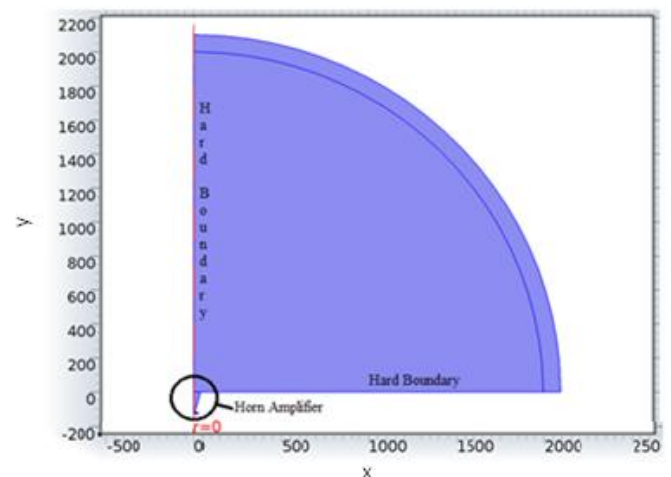

Fig. 4.   Horn amplifier of length 120 mm after applying boundary conditions

Figure 4 shows the model after applying boundary condition. It is found from literatures the movement of the diaphragm produces fluctuations in pressure, which act through a small cavity, the behavior of diaphragm is of great interest, more the deflection and acceleration louder will be the sound.

As the input FEA software needs acceleration of vibratory body. To find out the acceleration of vibratory body following equations are used.

$$y_o = \frac{3}{16}\frac{P\,(1-\theta^2)}{Et^3}R^4 \qquad 12$$

Where,
y_o = Amplitude in m
P = Input Pressure in N/m^2 (Pa)
θ = Poisson's Ratio
E = Young's Modulus in N/m^2
t = Thickness of Diaphragm in m
R = Radius of Diaphragm in m

This equation will give the maximum acceleration at different input pressure.

$$a_{max} = f_n^2 \text{ x } y_o \qquad 13$$

f_n = Natural frequency in Hz
y_o = Amplitude in m
a_{max} = Maximum Acceleration in m/s^2

Above calculation helped in finding out maximum displacement and maximum acceleration, which is most important factor as far as the FEA simulation is concerned. Matlab program is used to calculate displacement, frequency and acceleration.

Following is the table of acceleration of diaphragm for different input pressure.

TABLE III.   ACCELERATION OF DIAPHRAGM FOR DIFFERENT INPUT PRESSURE.

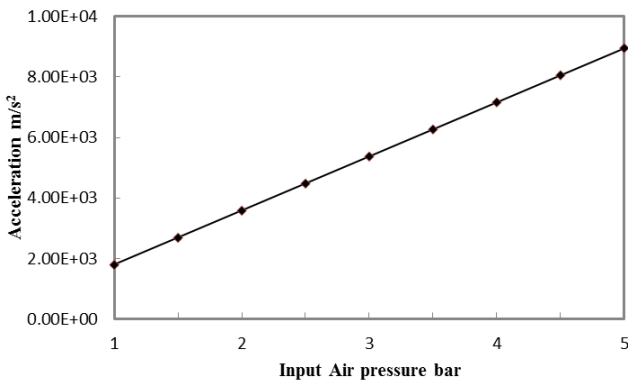| Sr No.	Frequency Hz	Acceleration m/s²
01	381.25	1.790e+003
02	577.90	4.114 e+003
03	794.54	7.776 e+003

Fig. 5.   Acceleration v/s Input Air Pressure Graph
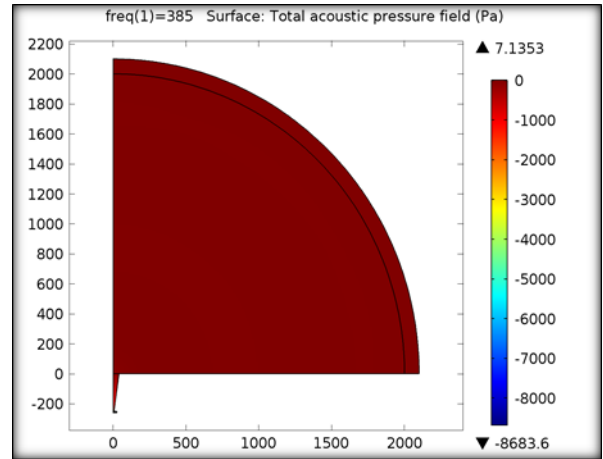
Now in Frequency table, from table III, enter the respective frequency for respective horn amplifier.
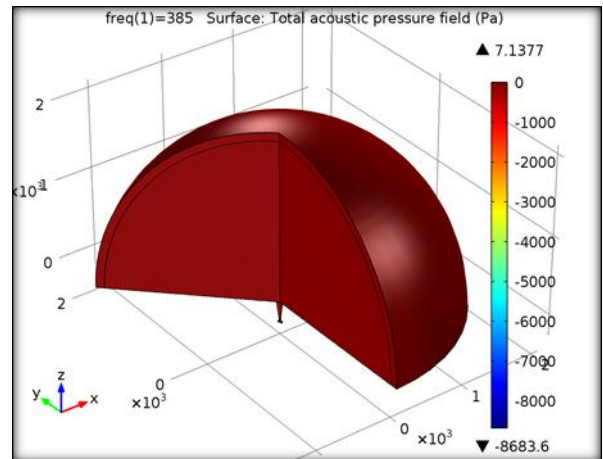
D.   Study Result

Following is the simulation result for type A horn amplifier for 1bar input air pressure.

E.   Acoustic Pressure

Simulation result for type A horn amplifier for 1bar input air pressure

(a)

(b)

Fig. 6.   Acoustic Pressure distribution

Sound pressure generated by supplying air at 1 bar pressure to sound generator, and pressure distribution is plotted at 2D and 3D in FEA software as shown in figure 6(a) and figure 6(b) respectively. From figure it can be concluded that acoustic pressure is high near to the sound generator and it get reduced as moved away from the horn mouth.
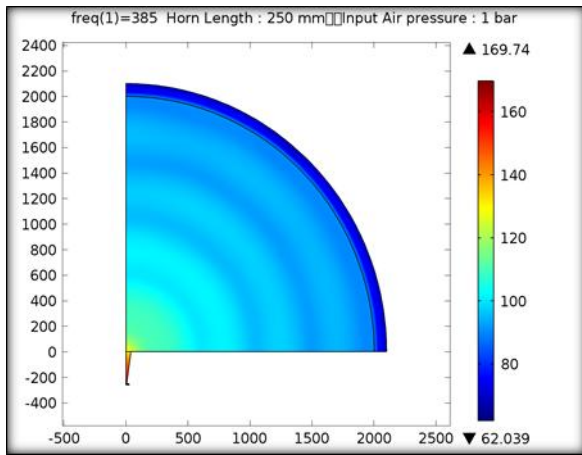
(a)
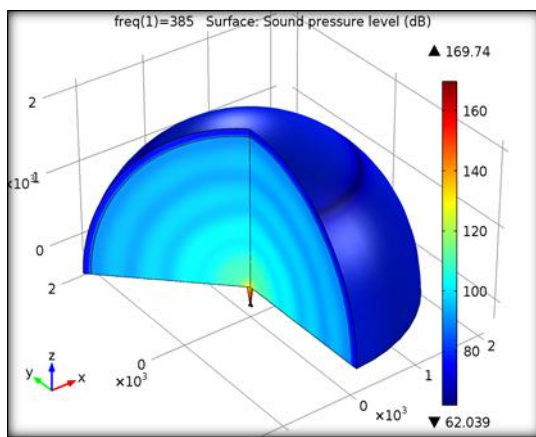
(b)

Fig. 7.   Acoustic Pressure Level distribution

Sound pressure level generated by supplying air at the pressure of 1 bar to sound generator, and pressure level distribution is plotted at 2D and 3D in FEA software as shown in figure 7(a) and figure 7(b) respectively. From figure it can be concluded that acoustic pressure level is high near to the sound generator and it get reduced as moved away from the horn mouth.

From literature and series of experiments it comes to know that sound fades i.e. its sound pressure level diminishes with increasing distance from its source. Once a certain distance from the source is exceeded, doubling the distance will reduce the sound pressure level by 6 dB.

From FEA software sound pressure level at different position approximately at 2m , 1.5m and 1m are extracted and given in table IV.

TABLE IV.   SOUND PRESSURE LEVEL AT DIFFERENT POSITION FROM HORN MOUTH.

x	y	SPL
15.25	1996.83	91.12
22.89	1500.46	93.13
15.25	1019.36	97.34

Similarly simulation is done for other horn amplifiers which are given table V.

TABLE V.   SOUND PRESSURE LEVEL (DB) GENERATED BY DIFFERENT HORN FLARE AT DIFFERENT AIR PRESSURE

Sr No.	Distance (m)	Sound Pressure Level (dB)
For Type A Horn		
1	2	91.12
2	1.5	93.13
3	1	97.34
For Type B Horn		
4	2	95.52
5	1.5	99.38
6	1	102.07
For Type C Horn		
7	2	107.05
8	1.5	108.15
9	1	113.47

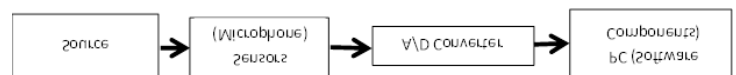## V.   EXPERIMENTAL PREDICTION OF SOUND FREQUENCY AND SOUND PRESSURE LEVEL

Fig. 8.   Block diagram of acoustic data acquisition setup

An experiments set-up is built to investigate the performance of different length horn amplifier. The experimental set-up consists of following components:

A.   Sound source producing system

Different sizes of horns are used as sound producing system, with same sound generator. The horn is blown by introducing compressed air in its sound generator chamber, which generates the sound of various frequencies. Details of all air horns are depicted in table 1.

Fig. 9.   Different air horns used in experiments

B.   Sensor

Bruel Kjaer make 4189-A-021 - ½-inch free-field microphone is used as sensor for this experiment which is as shown in the figure 10. Microphones are electroacoustic transducers which converts acoustic energy into measurable electrical signals. They serve two principal purposes. First, they are used for converting music or speech into electric signals which are transmitted. Second, they serve as measuring instruments, converting acoustic signals into electric currents which transmits and actuate indicating meters. In some applications like the telephone, high electrical output, low cost and durability are greater consideration than fidelity of

reproduction. While in other applications, small size and high sensitivity and low cost. In measurement applications it is interested to determine the sound pressure or the particle velocity. LabVIEW software is used to measure sensors output.

Fig. 10. Bruel Kjaer make microphone [24]

Fig. 11. Actual photograph of Microphone with holder

Features of selected microphone are [24]
Sensitivity: 50 mV/Pa
Frequency: 20 Hz – 20 kHz
Dynamic range: 16.5 – 134 dB
Temperature: – 20 to + 80°C (– 4 to + 176°F)

C.   Interfacing Devices

In Data acquisition through virtual instruments proper connection of sensor, A/D converter and display unit is an important task. As the microphone used in the system gives the output in voltage, this voltage (analog) must have to be converted into measurable signals. For this purpose following A/D converters are used.

Chassis (NI cDAQ-9172)

The NI cDAQ-9172 is an eight-slot USB chassis designed for use with C Series I/O modules. The NI cDAQ-9172 chassis is capable of measuring a broad range of analog and digital I/O signals and sensors using a Hi-Speed USB 2.0 interface.

Fig. 12. National instrument's cDAQ-9172 [25]

I/O Modules (NI 9234)

I/O modules are used to convert analog signal to digital signal. It converts voltage of 0-5 V to digital signals. NI 9234 has four BNC connectors that provide connections to four simultaneously sampled analog input channels.

Fig. 13. NI 9234 Module [25]

D.   Experimental Investigation

The main objective of setup is to measure the sound frequency and sound pressure level of different horn lengths. The experiment is conducted for different horn amplifier length at different distance from sensor. The setup and line diagram are shown in the figure 14 and in figure 15 respectively.

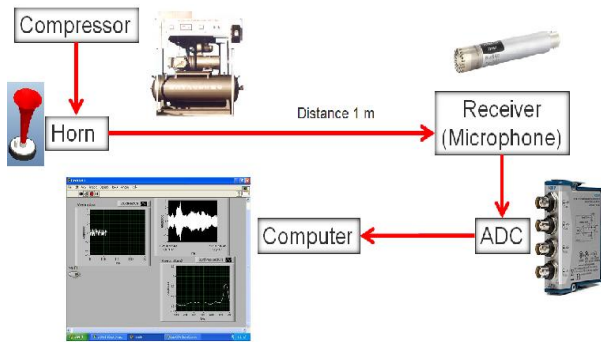Fig. 14. Actual setup for data acquisition of sound pressure

Fig. 15. Line diagram for data acquisition of sound pressure

After completion of proper connection, as per the requirement control panel and block diagram is designed. Figure 16 and figure 17 shows the control (front) panel and back panel used in experimentation.
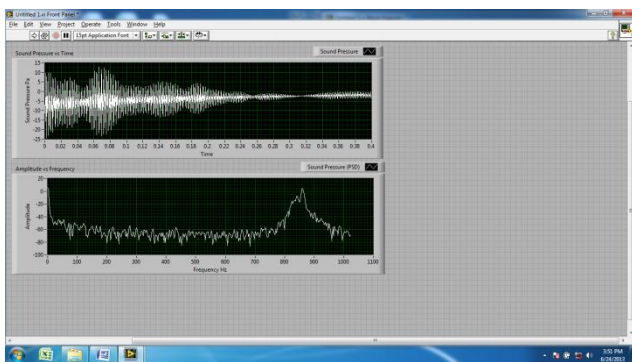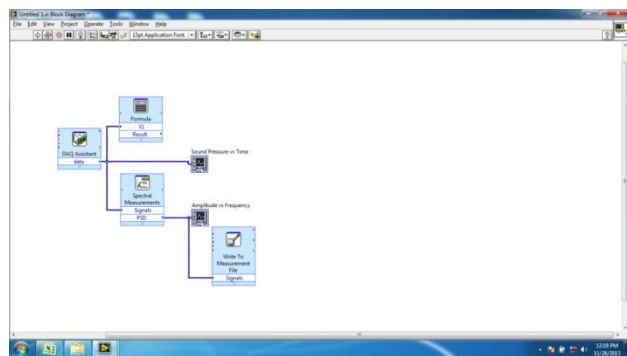

Fig. 16. Front Panel

Fig. 17. Block Diagram Panel for Setup.

To get the output from LabVIEW signals which are taken from the sensors are plotted on two graphs, one is sound pressure Pa v/s Time and second is amplitude v/s frequency by using FFT tool.

As data extracted from DAQ is in sound pressure Pa, it is converted into sound pressure level using equation 2 or equation 3, and this data is then plotted on sound pressure level v/s frequency graph. Same technique is used for type A, B and C horns at pressure 1 bar and distance of 1, 1.5 and 2 meters.

E. Prediction of Cut off frequency and sound pressure level

Initially experiments are conducted at the distance between sound source and sensor of 1 meter. The output data are collected and plotted on sound pressure level v/s frequency graph which is shown in figure 18.
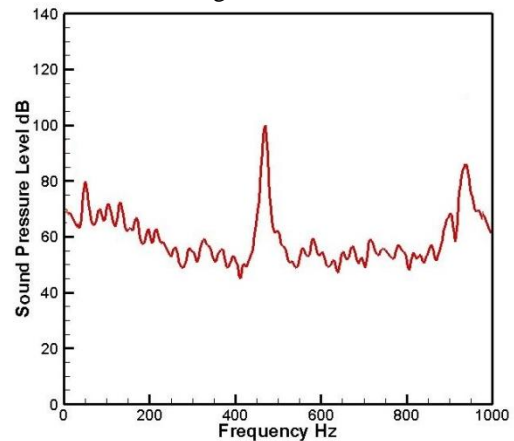

Fig. 18. Frequency spectra for horn amplifier for horn length 250 mm and input pressure 1 bar at a distance of 1 m

From graph the peak value at most influential sound wave frequency for different length of horn amplifier is extracted. This peak value can be taken as frequency of sound wave as well as sound pressure level generated at that particular frequency which is ultimately highest sound pressure level that can be generated by using particular horn amplifier. Sound frequency and sound pressure level predicted using data extracted from DAQ for different length of horn amplifier given in table VI below.

TABLE VI.   FREQUENCY OF SOUND WAVES GENERATED IN DIFFERENT LENGTH HORNS.

Sr. No.	Horn Length (mm)	Frequency (Hz)
1	150	850-900
2	165	600-650
3	250	450-500

TABLE VII.   SOUND PRESSURE LEVEL generated by different horn FLARE AT 1 BAR AIR PRESSURE

Horn Type	No.	Distance (m)	Sound Pressure Level (dB)
Type A Horn	1	2m	95
	2	1.5m	96
	3	1m	101
Type B Horn	4	2m	100
	5	1.5m	104
	6	1m	106
Type C Horn	7	2m	106
	8	1.5m	108
	9	1m	112

VI. RESULTS AND ANALYSIS

After extensive theoretical, simulation and experimental investigation data and result should be discussed to show the difference between all the methods which are adopted. In this chapter attempt is made to compare the results and data
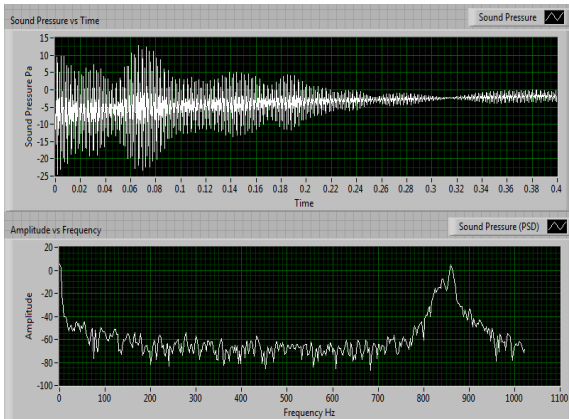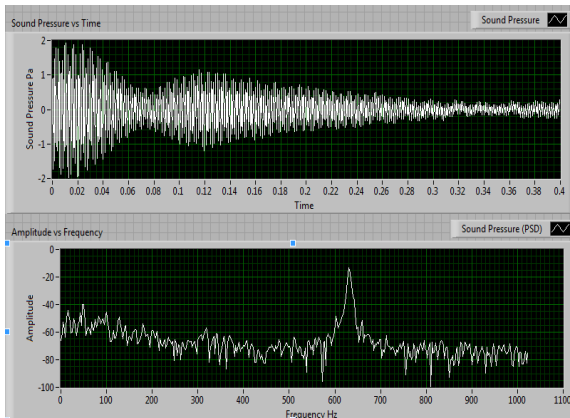

Fig. 19. FFT Graph for 150 mm length horn

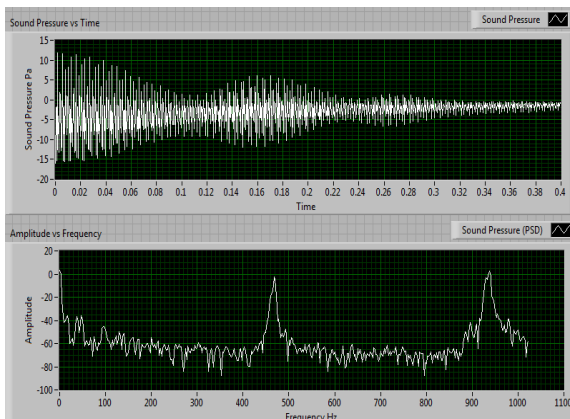Fig. 20. FFT Graph for 165 mm length horn

Fig. 21. FFT Graph for 250 mm length horn

From graph the peak value at most influential sound wave frequency for different length of horn amplifier is extracted. Frequency of sound which is predicted using DAQ for different length of horn amplifier.

TABLE VIII.   FREQUENCY OF SOUND WAVES GENERATED IN DIFFERENT LENGTH HORNS

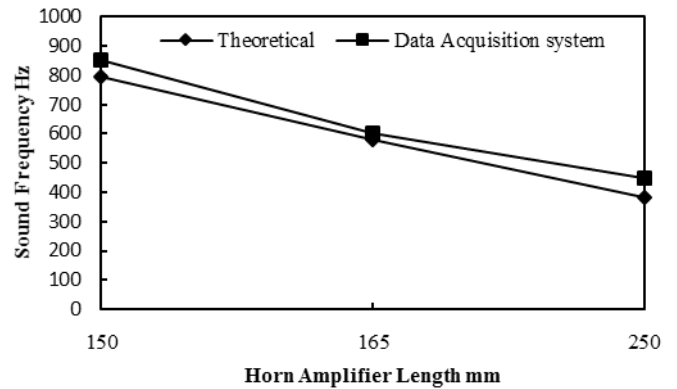| Sr. No.	Technique used for determination of frequency	Horn Length		
		150 mm	165 mm	250 mm
1.	Theoretical/MATLAB	794.54 Hz	577.90 Hz	381.25 Hz
2.	NI's Data Acquisition system	850-900 Hz	600-650 Hz	450-500 Hz

Fig. 22. Comparison of Sound frequency for different length horn amplifier.

In the table VII the approximate values of frequencies of sound waves for different horn length by using theoretical and experimental methods are compared. The variations in experimental and theoretical frequency values are acceptable, as the experiments are conducted in open environment.

A. Comparison of sound pressure level

Accurate measurement on dB scale is must, for this purpose simulation on COMSOL Multiphysics$^{©}$ environment and actual measurement using National Instruments Data Acquisition System is carried out.
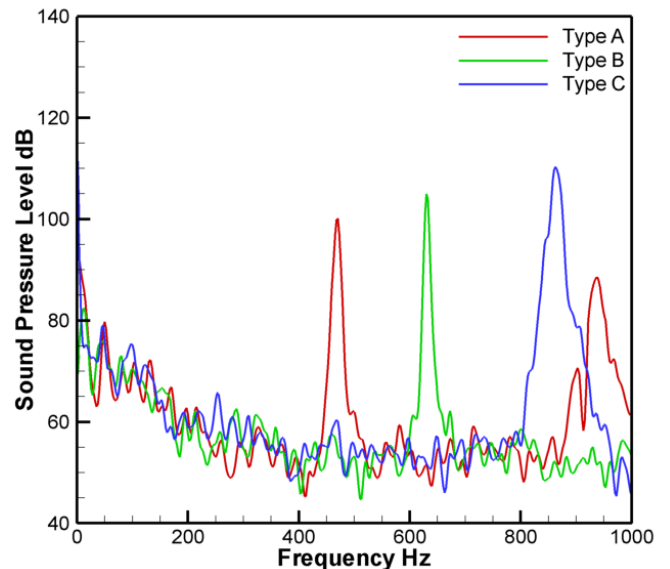

Fig. 23. Comparative frequency spectra for horn A,B and C for 1 bar internal pressure at a distance of 1m.
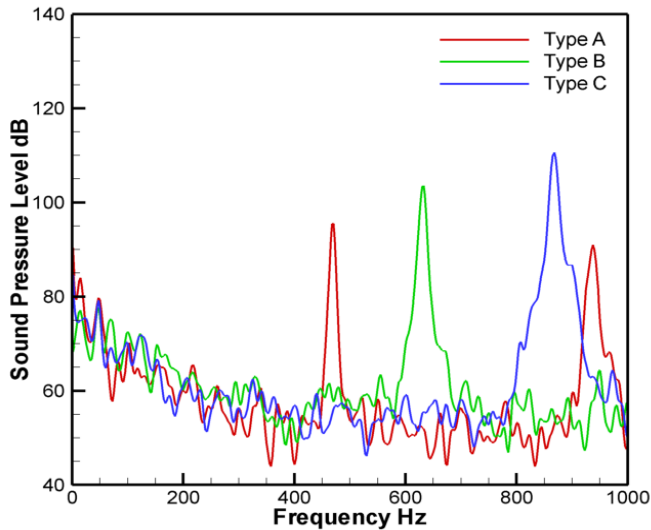
Fig. 24. Comparative frequency spectra for horn A,B and C for 1 bar internal pressure at a distance of 1.5 m.

Fig. 26. Comparative Histogram for Simulation and Experimental result comparison for different type of Horn.
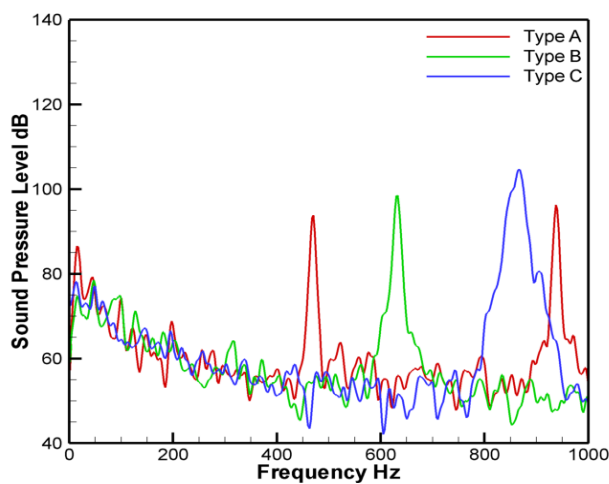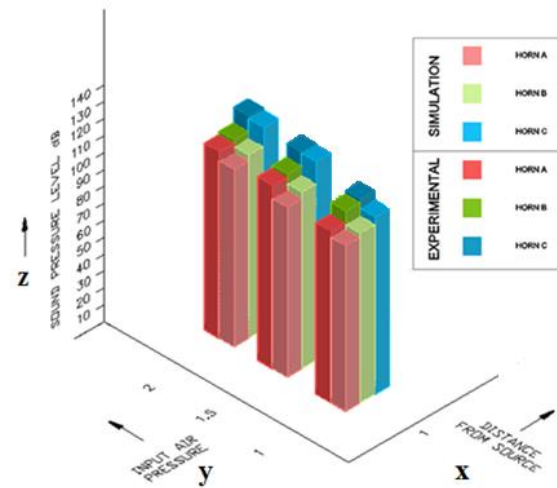

Fig. 25. Comparative frequency spectra for horn A,B and C for 1 bar internal pressure at a distance of 2 m.

TABLE IX.   SOUND PRESSURE LEVEL GENERATED BY DIFFERENT HORN FLARE AT DIFFERENT AIR PRESSURE

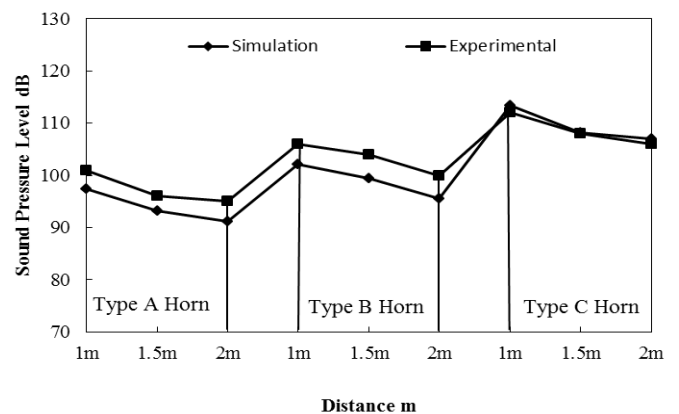| Sr No	Technique / Distance	Simulation	Experimental
For Type A Horn			
1	2m	91.24	95
2	1.5m	93.13	96
3	1m	97.34	101
For Type B Horn			
4	2m	95.52	100
5	1.5m	99.38	104
6	1m	102.07	106
For Type C Horn			
7	2m	107.05	106
8	1.5m	108.15	108
9	1m	113.47	112

Fig. 27. Comparison of sound pressure level generated through A,B and C horn amplifier for 1 bar internal pressure at a distance of 1, 1.5 and 2 m.

Figure 26 and 27 shows the graph which is plotted using readings from table IX. Graph shows approximate simulation and experimental results. Axis x shows the distance from sound source, axis y shows the input air pressure and axis z shows the sound pressure level of each horn. From above table and graph it can be predicted that maximum sound pressure level is occurred when type C horn is used at 2 bar air pressure, and it can be referred as experimental and simulation results are in good agreement.

VII.   RESULTS AND ANALYSIS

Sound pressure level and sound frequency prediction using theoretical simulation and experimental method is investigated in this paper. Theoretical analysis is done to find out acceleration of diaphragm of sound generator for different input air pressure and effect of length of horn amplifier on sound frequency, these values then used in FEA software to predict the sound pressure level at different distance. Experiments are conducted for same type of horn amplifiers and its values then compared with theoretical and simulation results. From theoretical, simulation and experimental analysis it is found that larger will be the length of horn amplifier lesser will be the sound frequency. And lesser the frequency larger will be the wavelength.

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