Apertures for Even Dispersion of Sound

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***Abstract*—The reflective property of sound was exploited in creating an aperture that can evenly disperse sound originating from a small speaker. The angle of the aperture was varied from normal, ten, twenty, and thirty degrees. Simulation and test were conducted for each model. Simulation was performed by modeling the speaker, aperture, and virtual space. The test was carried out using a sound generator and analyzer. Speakers produced a sound that was focused on a particular direction, a potential cause of warped performance, but the symptom could be relieved with the usage of apertures. The aperture lowered sound pressure at the top plane, while raising the measurements taken at the side planes. Overall, sound was redistributed to be more even. Sound distribution varied with the angle of the reflective surface, the decrease at the top plane was least in the thirty degrees model, while also increasing sound pressure at the side planes the most.**

Keywords—Acoustic aperture; Aperture angle; Reflection; Sound distribution; Sound wave

I. INTRODUCTION

Sound propagates in a linear fashion. Like light waves, sound waves are reflected, refracted. Within the room, perception of sound differs depending on position, because of the characteristics of sound. The physical parameters that govern sound frequency, sound pressure, and phase change as waves interact with the surroundings. Sound is measured by changes in air pressure, and sound pressure is the most important parameter when determining which sound is perceived to be louder. So if the sound pressure is low, it is quiet. And, when it is high, it is noisy. If the Sound Pressure Level reaches 85dB, it is interpreted as unpleasant for everyday activities [1]. The advent of sound recording and playback technology has also brought rapid development in manipulating quality and volume of the recorded sound. Modern sound recording technologies have flourished with the sudden growth of digital media, and the speakers that convey this recorded sound is again improving with the support of a few acoustics theories. Sound manipulation technologies recently have shifted its attention to sound's wavelike properties and the control of its focus by utilizing the said quality. Light can be focused or dispersed through the usage of optical lenses, and likewise, sound can be focused or dispersed through the usage of sound lenses. Research on sound lenses can be classified by its purpose[2-5]. The first class acts to redirect sound to a desired orientation and reinforce the performance of a speaker[6]. The second class focuses sound over an area, such that sound can be used in a setting that requires precision. This type of lenses are Fresnel lenses, and they consist of flat reflectors, conventionally metal, that are aligned to focus sound for usage in ultrasound sensors or sound microscopes[7]. Out of these two, the first class is more commercially used. For example, layers of board are placed on top of large horn type speakers, or ramp-like structures are attached on top of the speaker to achieve a surround sound effect[6]. So, there has been active researches on the topic, but the results have eluded themselves to expensive and specialized equipment.

The goal of this study is to use properties of sound waves like reflection, refraction, and transmission to manufacture an inexpensive yet effective aperture that may change the direction of sound. This is to expand the concept of acoustic lenses, mostly used for ultrasound or sound microscopes, to ordinary devices. Therefore, the target of the study will be on acoustic lenses designed for small Bluetooth speakers, which is popular among the majority of people. Bluetooth speakers, owing its popularity to the advent of smartphones and other IT technologies, are widespread indoors and outdoors. But, to keep an affordable price, a cylindrical structure has become a norm. However, this design directs sound up, whereas the actual users are at the surface. Like so, if sound is not evenly dispersed throughout the space, this might cause loss of sound quality, and might even be damaging to the auditory system. This research set the aperture's appearance as a parameter of how well it would disperse sound evenly throughout a sample space.

II. PHYSICAL CHARACTERISTICS OF SOUND WAVE AND ACOUSTIC LENSES

Sound is a sort of wave and has a set amount of energy. When sound meets a medium of different density, a transfer of energy occurs in the form of reflection, absorption, and transmission [8]. As in fig.1, when sound wave meets a medium, a part of the incident energy is absorbed, thus referred to as the absorbed energy. Some are transmitted through the medium, thus called the transmitted energy. Therefore, the reflected energy can be referred to as such.

$$\mathrm{P_r} = P_t + (P_t + P_a) \quad (1)$$

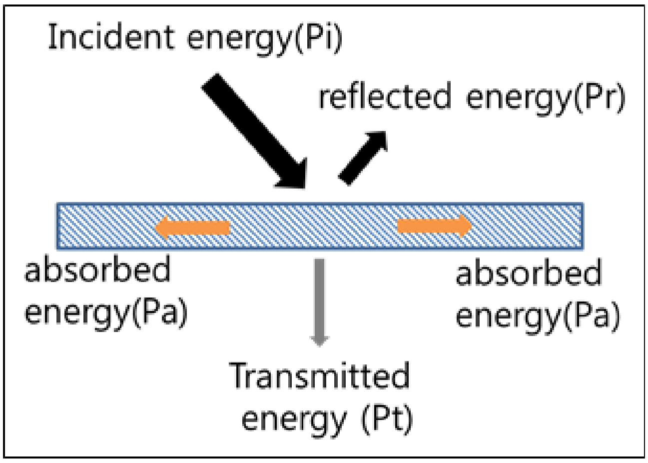


Fig. 1 *Sound Energy Transformation*

Therefore, to maximize sound return (reflected energy) in the presence of a medium, it is necessary to minimize absorption and transmission. Since this depends mostly on material, various sound insulators are under development for this purpose. When sound propagates, sound pressure is inversely proportional to the square of the distance from the point source of sound.

III. APERTURE DESIGN AND ANALYSIS

A. *Aperture Design*

Considering the characteristics of sound, aperture for even dispersion of sound was designed. Material and design were two main key factors that had to be determined. It was a priority with the material that loss of sound energy was minimal. At the same time, design had to be optimized for even dispersion of sound.

The important factor in aperture design is finding the structure that redirects and evenly distributes concentrated sound appropriately.

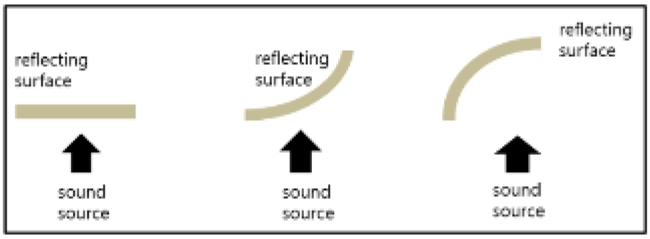
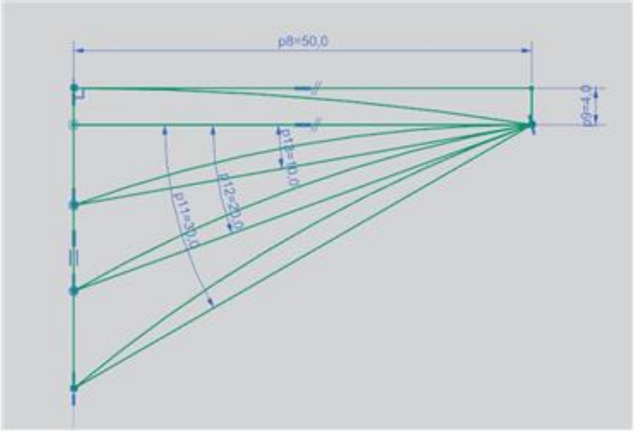
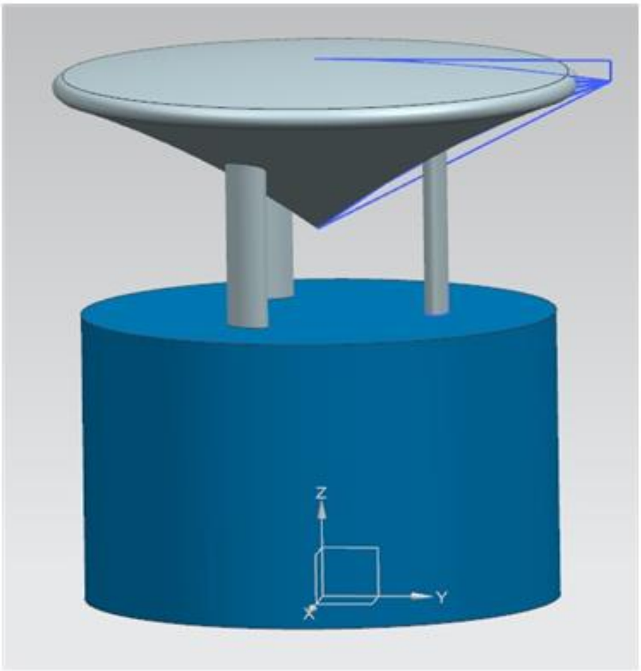


Fig. 2 *Reflected Surfaces*

There are a variety of surface types that can be effective for sound reflection. For the simulation, planar, angled, and curved surface were considered. But, curved surface was chosen as it will be effective for the purpose of sound reflection. Especially, curved surface with the concave curvature was chosen. As shown in fig.2, concave surface approaches planar plane at the end. So it has properties of both curved and planar surface. Based on this reasoning and multiple design reviews, the final design for this simulation and test was chosen to be curved surface with concave curvature, as shown in fig. 3.



(a) Shape sketch of aperture



(b) Design shape of aperture

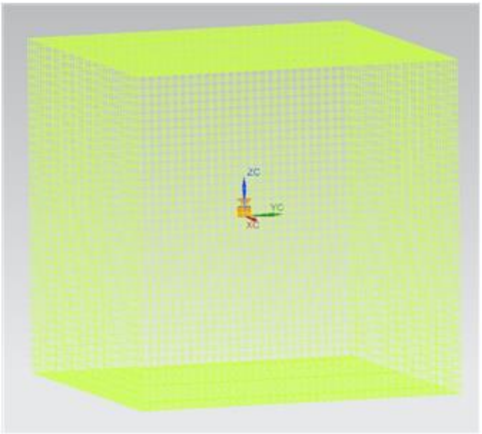
Fig. 3 *Aperture Design*

As the top surface is a planar surface, referencing the angled line at 0°, 10°, 20°, and 30°, respectively, a line is drawn as the side of triangle. By revolving this section for 360°, a cone shaped 3D design is formed. The reason for not going any steeper than 30°was because the resultant surface already had formed enough angled surface to be sufficient.

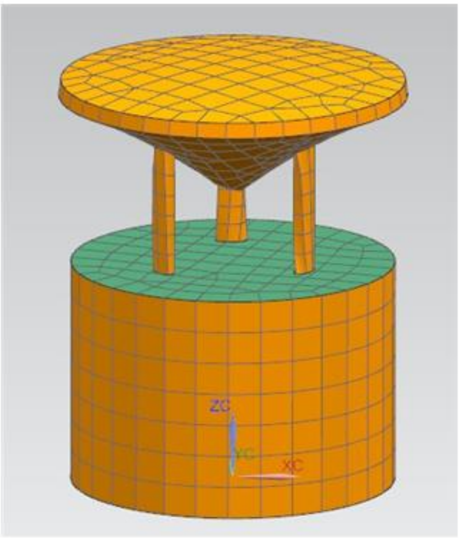
B. *Acoustic Analysis*

1) *Analysis Model and Approach*

To simulate the effectiveness of the aperture in uniform sound dispersion, a professional program for acoustic analysis was used. For this analysis, program called NASTRAN was used.



(a) Virtual volume modeling



(b) Speaker and aperture modeling

Fig. 4 *Acoustic Analysis Modeling*

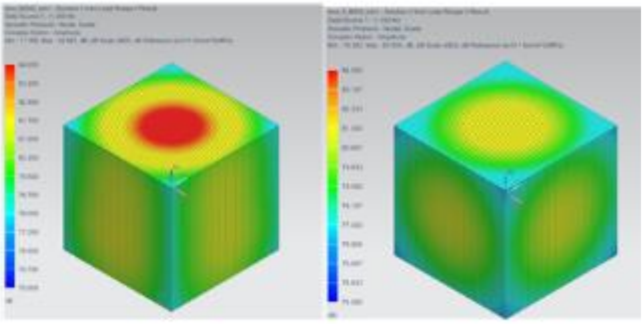
A virtual volume of the size 2m X 2m X 2m was chosen to monitor the variance of sound for different apertures. This simulation program, for solving problems of engineering and mathematical physics, is based on the Finite Element Method. The model is divided into smaller units interconnected at nodes to two or more elements. For this analysis, mechanical properties to simulate the aperture test case for the chosen material (table 1) is specified. The uniform sound pressure of 85dB was set as the input value for the speaker. The reason in selecting 85dB is because this is the decibel level that people feel as unpleasant to listen to [1]. The goal of the simulation was to analyze the variation of output sound pressure variance at the top and side surfaces of speaker when placed at the virtual volume space and exposed to 85dB input sound pressure.

Properties	Values
Young’s modulus	3 Gpa
Mass density	1.3 kg/m3
Poisson’s ratio	0.37
Yield strength	27 Mpa

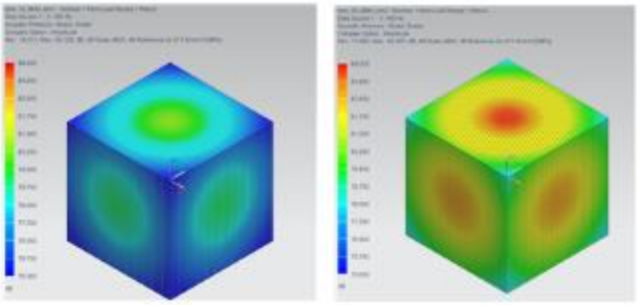
Table I Mechanical Properties

C. Simulation Results

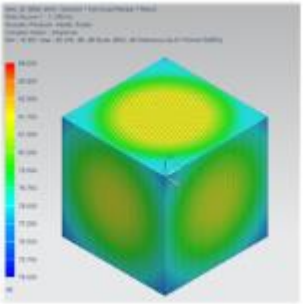
Sound pressure variance results for different models are shown in fig.5. The distribution of sound pressure differed with the usage of apertures. As shown in ‘(a) no aperture' case, sound pressure is focused to the top area if aperture is not used. But, if aperture is placed, sound pressure is distributed while sound pressure at the top surface is reduced. In all cases, sound pressure distribution on the top surface appears as a symmetrical pattern. On the side, the maximum value of sound pressure varies according to aperture types. For a detailed comparison of sound



(a) no aperture (b) angle 0



(c) angle 10 (d) angle 20



(e) angle 30

Fig. 5 *Sound pressure within sample space for each aperture* pressure variance according to aperture design, actual values of sound pressure near the top and side of virtual space was analyzed.

Referencing speaker location, the top and side surface of the virtual volume was divided by every 20cm. Sound pressure values for each section were obtained.

Aperture angle	**Distance from origin**					
	0 cm	***20 cm***	***40 cm***	***60cm***	***80 cm***	***100 cm***
base	84.9/80.6	84.0/80.6	83.6/81	82.5/80.5	81.0/80.5	80.0/80
0	81.6/80.9	81.2/80.7	80.9/80.5	80.5/79.2	79.0/78.5	78.0/77.0
10	80.2/79.2	79.4/78.5	79.2/78.0	78.5/77.0	78.0/76.0	76.0/75.0
20	83.8/82.5	83.0/81.5	82.5/81.0	82.0/80.0	80.0/79.0	79.0/78.0
30	82.5/81.0	82.0/80.7	81.5/80.5	81.0/80.0	80.0/79.0	78.0/77.0

Table II *Sound pressure level along virtual volume along lateral path.*

Table 2 summarized these sound pressure values. For the virtual volume, variations in sound pressure levels according to design change with different aperture angle could be obtained and plotted as a graph in Fig. 6.

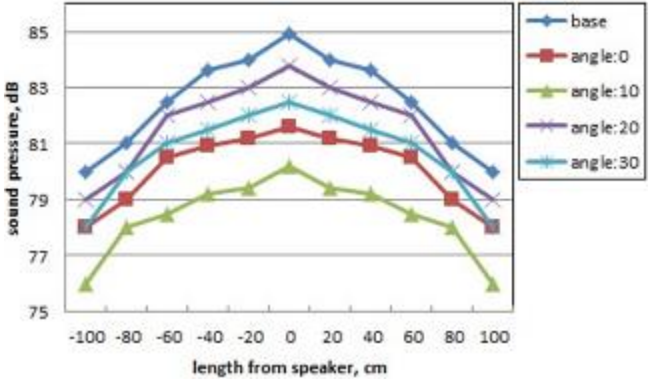


Fig. 6 *Sound pressure level at top surface*

The origin of the horizontal axis represents the position of the speaker. Sound pressure values on the side of virtual volume were highest at 84.9dB when aperture was not placed. Sound pressure level was the lowest with the 10 degrees model. Smaller angles resulted in the lower sound pressure values. Regardless of aperture design, the highest sound pressure was at the top center. The largest reduction of sound pressure value was about 4dB, and this proves that sound is dispersed. Based on the maximum value, 4dB is about 5% reduction, which is not very significant. But, comparing between sound distributions, the use of aperture is quite significant. If aperture is not placed, as in (a), sound pressure values are more focused. But, if aperture is used, as in (b) ~ (e) case, sound pressure values are spread out throughout top and side. The difference in sound pressure values in the virtual volume without an aperture was about 5dB; however, with the 10 degree aperture, pressure difference value was only 2.8dB. This implies that sound is more evenly distributed when the aperture is in use.

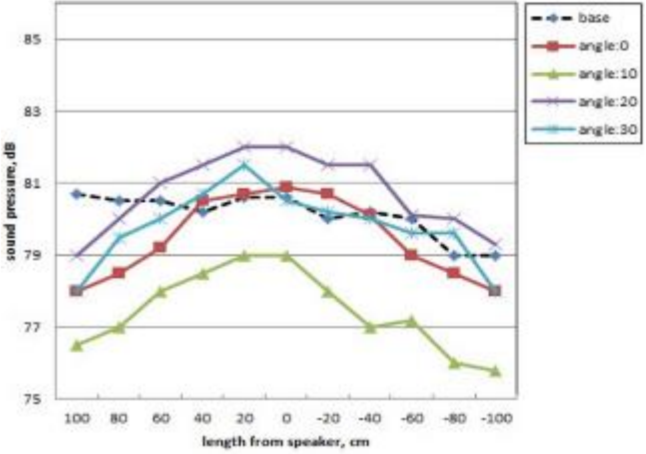


Fig. 7 *Sound pressure level at side surface*

Simulation results on the side of virtual volume is somewhat different from that of the top. While sound pressure distribution at the center of the top is quite symmetric, sound distribution on the side is not so. Disregarding the zero degree model, the peak values were slightly above the center point. The exception seems to be result of the aperture redirecting most of the sound headed in the vertical. As shown in Fig. 7, sound pressure level of the side differs between cases. When aperture is not placed, the 'base' line, sound pressure is the highest at the point close to speaker top. As it approaches the center, sound pressure value is lowered. This proves that sound energy is more concentrated at the top area and that the transmission of sound energy is less toward the side if aperture is not in use. Considering that speaker sound is heard mostly from the side, this is loss in performance. Utilizing the aperture, sound loss and dispersion can be improved. For all designs, sound pressure increased when approaching the top. This is due to reflection; speaker sound directed to the top gets reflected to the side. From the simulation, we may conclude that such an aperture can be an effective tool in dispersing sound evenly.

IV. APERTURE MANUFACTURING BY 3D PRINTER

After FEA Simulation, the designed aperture was manufactured for the experiment using a 3D Printer.

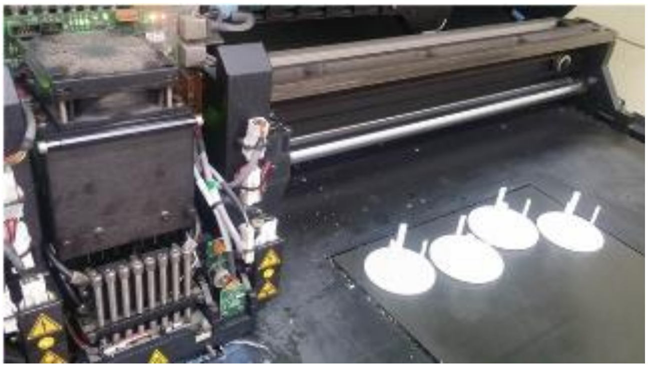


Fig. 8 *Aperture manufacturing through 3D printer*

Light plastic material was chosen for manufacturing. This type of material is competent in minimizing sound absorption and transmission. Fig.8 shows the manufacturing process using a 3D printer. And, fig.9 shows the finished aperture placed on top of speaker.

Fig. 9 *Finished aperture on top of Speaker*

V. EXPERIEMT

A. Experiement Set-up

To investigate the sound control effects of the manufactured aperture, an experiment setup was prepared as fig.10. The generation and analysis of sound was accomplished electronically. It is common that expensive sensors are used in research of sound, but recently, sound generation and analyzation apps designed for smartphones have proved useful and have procured some promising research results[9-10]. Tones were generated through Bluetooth speakers and analyzing sound pressure and frequency at the desired location.

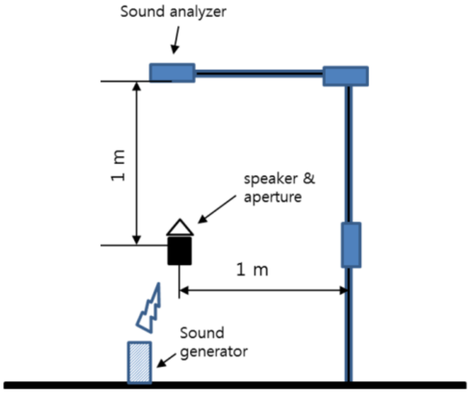


Fig. 10 *Schematic of Acoustic Test*

B. Experiement Procedure

The experiment was carried out as such. The tone set by the Sound generator is transmitted through the Bluetooth speaker. Sound was set to be at 70dB at 400Hz. The conditions of the input differed from analysis because small speakers have uneven volumes at high output settings due to battery usage. At 70dB, sound pressure could be held constant for a stretch of time. When the speaker made the set tone, sound analyzers were used to measure sound pressure from a meter away. Measurements were taken from the horizontal and vertical positions for all apertures.

C. Test Results

Results are measured from two directions, vertical and horizontal, respectively. Table 3 is the data from the experiments. Measurements are taken before and after the speaker is equipped with apertures. The difference between two instances are recorded.

aperture angle	**Base**	***0***	***10***	***20***	***30***
top plane	***71,3***	70.0/ 69.5	70.1/69.5	71.2/ 70.6	70.5/69.3
		0.5	0.6	0.6	1.2
side plane	***63.3***	63.3/65.0	63.3/ 65.0	63.1/ 63.4	62.0/ 64.2
		-1.7	-1.7	-0.3	-2.2

Table III shows results in Db.

Fig.11 shows the change of sound pressure. Sound pressure decreased at ceiling around 0.5 to 1.2 dB, a smaller margin compared to the acoustic analysis, as the aperture was placed. The side plane, in contrast to the ceiling, showed an increase of sound pressure as the aperture was used. Fig.12 shows the difference of sound pressure according to the existence of the aperture. From fig.12, it is seen that there is an increase of sound pressure concerning side planes, and this trend is in line with the analysis results.

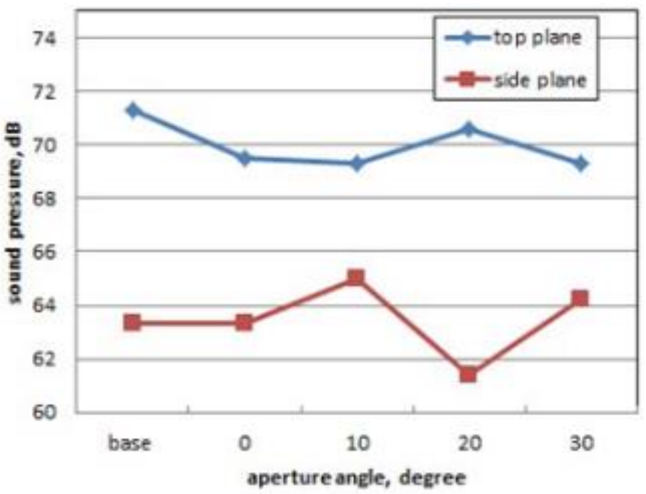


Fig. 11 *Sound pressure along planes*

There was no particular correlation with the structure of the aperture, but it could be verified that sound pressure at the sidelines always increased. The reason for the change is that the sound waves are reflected off of the aperture.

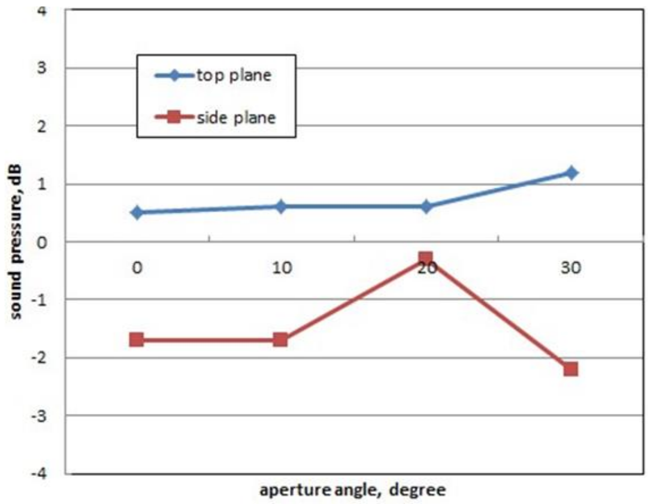


Fig. 12 *Sound pressure variation in respects to no aperture*

In the absence of any apertures, the produced sound waves are directed towards the ceiling; however, when the aperture is used, sound waves are redirected towards the sidelines. The crudeness of the setup was problematic in acquiring further data, but it could be verified that this aperture can manipulate the overall sound distribution.

VI. DISSCUSSION

Through simulation and experiments, it is concluded that an aperture can be an effective tool in dispersing sound evenly. But, to obtain more precise results, the following items should be considered.

a) For the simulation, professional FEA(Finite Element Analysis) program for acoustic analysis was used. But, it was limited to expand to exact parameter study by interpreting physical phenomena and analyzing mathematically. During the follow-up research, it seems essential to derive governing equation and perform parameter study.

b) The structure of the aperture is important in controlling the direction of sound. An effective structure must be verified through an experiment, yet the one conducted in this research was done in an ordinary room, and this posed a limitation in accurately surveying sound distribution. According to Fig.14 results were not even with the kind of aperture used. It is speculated that this effect is the limitations of the experiment. More detailed experiments, for example using anechoic chamber and acoustic sensors are necessary for further improvement.

VII. CONCLUSIONS

A specific aperture was manufactured through acoustic analysis and experiment with the purpose of evenly distributing sound. The findings are as follows.

a) It is common in small speakers that sound was only directed up. Resulting in a sound distribution that is unbalanced and top heavy, enough to warp and distort sound. However, it was verified that the aperture could effectively manipulate the direction of sound waves to evenly distribute sound.

b) The aperture redirected sound towards the side planes and increased sound pressure where the listeners would generally be.

c) Distribution of sound on the ceiling was symmetrical with disregard to the angle of the aperture. Without the aperture there was almost a 5dB difference, yet this was almost halved to 2.8dB with the aperture.

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