Skyline quadratic residue diffuser-resonator (SQRD-R): a study about its characteristic

Suyatno1*, M Lianto2
1,2 Physics Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
1 kangyatno@physics.its.ac.id

Abstract. To create a comfortable acoustic environment both indoor and outdoor, we need to control the noise. In the room, noise comes from both outside and inside the room for example is flatter echo. Installation of acoustic material such as absorber, resonator, or diffuser is an example of indoor noise control. QRD is one of diffuser consider of wells with different depth to diffuse the reflected sound. The depth of the wells is calculated by DR. Manfred Schroeder formula. In this research, a combination of Skyline QRD and Helmholtz resonator is given, we call it SQRD-R. This SQRDR follows the design from Wes Lachot Design but using a Helmholtz resonator as the cell. The examination of its characteristic is built using both of impedance tube test and calculation. The purposes of this research are learning about the effect of holes position on its sound impedance and sound absorption coefficient. The highest impedance value is \(-j(3.5 \times 10^7)\) acoustic ohm. The highest absorption coefficient is 0.9. By controlling the SQRD-R dimension, we can control noise at specific frequency.

1. Introduction

We need to control noise to create a comfortable acoustic environment both indoor and outdoor. Noise is a sound that occurs at an incorrect time and place. According to WHO [1], noise can interfere the communications, cause physiological until psychological problems. Noise also causes some health problems for man and also disturbs the comfort of the environment [2].

Some examples of noise control that we know are acoustic barrier installation, the use of acoustic material like reflector, absorber, resonator, and diffuser. The use of each material based on what kind of problem we found in the room. To diffuse the sound wave but not reduce the energy we use diffuser [3]. In application, a diffuser is used to repair the sound deviations in room like flatter echo that caused the noise. Figure 1 is an example of diffusers.

Figure 1. The example of diffusers.
Figure 1 shows some type of diffuser, one of them is Quadratic Residue Diffusers (left). One of the criteria that can be used as a characteristic diffuser assessment is the scattering pattern [4]. QRD (Quadratic Residue Diffusers) is a panel considering wells with different depths to diffuse the reflected sound. This equation calculates the depth sequent of the wells (Sn):

\[ S_n = (\text{well position})^2 \mod N \]  

(1)

Where N is the number of wells and it must be a prime number. This formula is developed in 1970 by Dr. Manfred Schroeder.

The minimum wavelength that will be scattered by the QRD based on its width (w).

\[ w = \frac{\lambda_{\text{min}}}{2} \]  

(2)

And the depth of the well is calculated by this equation,

\[ d_n = \frac{S_n \lambda_0}{2N} \]  

(3)

where \( \lambda_0 \) is a controlled wavelength.

1.1. Well depth sequent calculation

For N=7, well number of QRD is shown below.

![Well number configuration of QRD.](image)

Figure 2. Well number configuration of QRD.

From figure 3, we can see how the well is numbered. The number starts from zero. For well number equal to zero, this is the calculation using equation (1).

\[ S_n = (\text{well position})^2 \mod N \]

\[ S_n = (0)^2 \mod 7 \]

\[ S_n = 0 \]

For well number = 1, the calculation becomes like this.

\[ S_n = (1)^2 \mod 7 \]

\[ S_n = 1 \]

We can look at the well depth calculation using quadrat and the residue of division, so it called Quadratic Residue. With same calculation, we got all the well depth calculation in order from zero to six is 0,1,4,2,2,4,1.
1.2. SQRD-R Specification

SQRD-R use our well depth sequent calculation and made it into 2-dimension sequent follows Wes Lachot Design. This is the complete sequent of SQRD-R.

\[
\begin{array}{cccccc}
4 & 3 & 0 & 4 & 3 & 0 & 4 \\
3 & 4 & 1 & 3 & 4 & 1 & 3 \\
0 & 1 & 4 & 2 & 4 & 1 & 3 \\
4 & 3 & 2 & 4 & 3 & 2 & 4 \\
3 & 4 & 2 & 3 & 4 & 2 & 3 \\
0 & 1 & 4 & 1 & 3 & 4 & 1 \\
3 & 4 & 1 & 3 & 4 & 1 & 3 \\
\end{array}
\]

**Figure 3.** Complete sequent of S-QRDR, the depth of the well is the sequent times 3 (we get from equation 3) and the height of the cell (Helmholtz Resonator) is 12 cm minus the depth. The red cycle is the area we use to measure the sound absorption coefficient in impedance tube.

Based on figure 3 we know that the highest cell is 12 cm, and the shortest cell is 3 cm, 4 in the sequent means there is no cell in SQRD-R. Every cell’s base dimension is 1.5 cm x 1.5 cm with the width of the cell is 1 mm.

2. Resonator

Resonator is a volume that has a resonance hollow where sound wave that trapped in it will be reflected many times and the energy is absorbed until zero. Resonator usually used as a sound absorber [5]. One kind of resonator in continuous development is Helmholtz resonator. To analyze Helmholtz resonator, we can use the illustration of equal parameter analysis [5].

This illustration is to analog the Helmholtz resonator with R-L-C series electric circuit. The analogy can be seen in figure 3. The resonator system consists of acoustic resistance \( R_A \), acoustic mass \( M_A \), and acoustic constant \( C_A \).

\[
\text{Figure 4. Equivalent circuit diagram, Helmholtz resonator (left) and RLC circuit (right)}
\]

From figure 4, we can understand that acoustic pressure is analog to electric potential [6]. We can also look for the impedance using equation (4).

\[
Z = R_A + j \left( \frac{\omega M_A}{1} - \frac{1}{\omega C_A} \right)
\]  

(4)

In this research, we can abandon the value of \( R_a \) in SQRD-R, so the value of \( Z \) only depends on \( \omega, M_A, \) and \( C_A \).

The value of \( M_A \) and \( C_A \) are

\[
M_A = \frac{\rho A L \pi}{\pi a^2}
\]

\[
C_A = \frac{V}{\rho_0 c^2}
\]

(5)

(6)
where $L_e$ is a length of the neck and $\rho_0$ is a density of air. Resonance happens when $\left(\omega M_a - \frac{1}{\omega c_a}\right) = 0$, so

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{M_a c_a}}$$

(7)

$f$ is resonance frequency.

3. Resonator-diffuser

To combine resonance and diffusion function in one panel is the idea of resonator-diffuser. Resonator-diffuser is a resonator panel that can absorb sound at its resonance frequency and the same time it will scatter the sound because of its surface geometry. In 2018, Suyatno et al did the preliminary study resonator-diffuser from PVC. The result shows that the resonator diffusor can absorb sound at its resonance frequency and also scatter the sound [7]. In 2019, Indrawati et al researched for coconut shell ability as resonator diffuser to absorb and isolate sound. It tells us that above 1000 Hz, the NR value is increased, and the panel absorbs sound around 250 Hz [8].

In this paper, we combine Skyline QRD with Helmholtz Resonator and we call it SQRD-R. The 2D pattern follows a design from Wes Lachot design. Ideally SQRD-R can increase the characteristic of the QRD because of the resonance. In this research we will study about the effect of holes position on sound impedance and sound absorption coefficient. The parameters was investigation are acoustics impedance and absorption coefficient. The measurement was conduct by using the impedance tube methods and analysis using a Yoshimasa Electronis sound analyzer.

4. Methodology

The SQRD-R as explained before was printed using PLA as the material and we prepared it to be measured using impedance tube. Based on figure 3, the dimention of resonator (cell) with variation height were 12 cm, 9 cm, 6 cm, and 3 cm. Every cell’s base dimension was 1.5 cm x 1.5 cm with the width of the cell was 1 mm. The diameter of the hole was 7 mm. The diameter of the circle base was 8 cm. There were two kinds of SQRD-R that we produced, first with holes on the top of panel and the second one is a panel with holes on the side. This is the figure of SQRD-R.

See at figure 5, the solid material of usual SQRD was changed by Helmholtz resonator. The diameter of the hole was 7 mm. This is the preparation for measurement.

Figure 5. SQRD-R design
Figure 6 is the set of measurement using the impedance tube. We use this equation to get the absorption coefficient.

$$\alpha = \frac{4P_{\text{max}}P_{\text{min}}}{(P_{\text{max}} + P_{\text{min}})^2}$$  \hspace{1cm} (8)

$P_{\text{max}}$ and $P_{\text{min}}$ in equation (8) are the maximum and minimum acoustic pressure inside the tube. To get the $P_{\text{max}}$ and $P_{\text{min}}$, the microphone must be driven along the tube. Then, we will compare the sound absorption coefficient between two SQRD-R panels. While the SQRD-R impedance value is calculated using equation (4).

5. Result
To determine the acoustic performance of the SQRD-R panel, calculations and measurements are made. The calculation was carried out to obtain the acoustic impedance value and resonator frequency of each resonator. In SQRD-R panel, all resonators compacted into one panel difuser. Acoustic impedance of each resonator was calculated by using equation (4) and the resonance frequency was calculated by using equation (3). Figure 7 shown the acoustic impedance for 4 variation of resonator.

Base on the figure 7, the acoustics impedance of SQRD-R for 3 cm hight have a acoustics impedance was smallest than the other. As a resonator, the resonance frequencies calculated by the equation (3). The resoanance frequency for each resonator are 953 Hz for 12 cm height, 2747 Hz for 9 cm height, 3364 Hz for 6 cm height, and 4757 Hz for 3 cm height. These resonators compacted in one diffuser.
As a panel resonator - diffuser, the presence of a hole in each blade causes the sound to be trapped so that its intensity is reduced. This value of the absorption coefficient measurement shown in Figure 8.

![Graph of SQRD-R Absorption Coefficient](image)

**Figure 8.** The Graph of SQRD-R Absorption Coefficient

From figure 8 we know that the absorption coefficient of SQRD-R holes on the top is different from absorption coefficient of SQRD-R holes on the side. Why it is different is discussed in discussion.

6. **Discussion**

Impedance in electrical circuit tells us about the flow of the electric current in the circuit. Analog to that case, acoustic impedance tells us about the flow of sound velocity through the holes and also the sound missing in the cavity. The greater the acoustics impedance value, the greater its ability to reduce sound, and vice versa. From figure 7, we know the acoustic impedance above 500 Hz almost zero. It means that the sound at low frequency is resisted at the hole of the cavity. The impedance values also tell us that resonator in SQRD-R worked.

The highest impedance value is \(-j(3.5 \times 10^7)\) acoustic ohm. It is the impedance of 3 cm height at 125 Hz. From impedance, we move to absorption coefficient. Both of SQRD-R that has been made has a same impedance and resonant frequency by calculation. But, from figure 8 we know that it has a different absorption coefficient. The absorption coefficient for SQRD-R with hole at the top surface, the highest absorption coefficient is around 2700 Hz which is its a resonant frequency. But it has different range of high absorption coefficient with the side hole. This shows that the position of the hole can affect the absorption coefficient value of the material on the incoming sound energy.

The value of absorption coefficients between 0 to 1. If the absorption coefficient is 1, it means the panel is perfectly absorbs the sound. If we analyze the effect of the holes position in its absorption coefficient, we know, in the impedance tube the top surface of SQRD-R receives the reflected and also the direct sound from speaker it different if the hole at the side of the panel. It will receives only the reflected sound inside the tube and we know, if the hole is on the side of panel it produce a better absorption.

The top surface of the SQRD is the place where the reflected sound will be scattered. So, the position of the hole on the top surface causes less reflected sound. So that it causes the sound absorption value caused by the SQRD panel. Therefore, for better resonance, it is recommended to make holes on the side of the panel. so that the role of the reflected plane on SQRD-R through its surface is not disturbed.
Referring to Figure 8, the line will touch a high absorption coefficient around its resonant frequency. The high absorption coefficient is 0.9, which is a hole in the side panel at about 2000 Hz. So, by controlling the cavity volume, width, orifice diameter as well as the hole position, we can control the noise at the frequency we need.

7. Conclusion

SQRD-R has acoustic impedance values. It indicates that the resonator is worked. The highest impedance value is $-j(3.5 \times 10^7)$ acoustic ohm. It is the impedance of 3 cm height at 125 Hz. The position of holes impacts the absorption coefficient. Holes at the side of panel produce a better absorption. The highest absorption coefficient is 0.9, that is hole at the side panel around 2000 Hz. we can control the noise at the frequency that we need by controlling the SQRD-R dimension.

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References

[1] WHO, “Occupational Noise”, Geneva: Protection of the Human Environment WHO, 2004
[2] Indonesian Ministerial of Environment Decree number: kep48/menlh/11/1996 About Noise Level Standart, (1996)
[3] Leslie L, Doelle & Dra. Lea Prasetio, M.Sc., Akustik Lingkungan, Mc Graw-Hill Book Company:New York, 1972, As
[4] D’Antonio P, TJ Cox, 2004, Acoustic absorbers and difuser : theory, design and application, Spoon Press : London
[5] Howe, M.S. 1976. On the Helmholtz Resonator. *J. Sound Vibr.* 13:427-440 J.P. Dowling, “Sonic band structure in fluids with periodicity density variations,” *J. Acoust. Soc. Am.* 91, 2539-2543 (1992)
[6] Barron, Randall F, 2001, Industrial Noice Control and Acoustic, Marcel Dekker, Inc. USA
[7] Suyatno, Andi A., Indrawati S. and Prajitno G.” The Study of Resonator-diffuser acoustics performance using PVC pipe”. Surabaya, Indonesia: Institut Teknologi Sepuluh Nopember, Applied IOP Conf. Series: Journal of Physics: Conf. Series 1075 (2018) 012055. doi:10.1088/1742-6596/1075/1/012055. 2018
[8] Indrawati, susilo & Suyatno, S & Yuwana Lila, 2019, the ability of coconut shell as refuser to absorb and isolate sound. Journal of physics and its application.15.66.10.12962/j24604682/v15i2.5244.