Quadratic residue diffuser-resonator (QRD- R) N7: design development of QRD using helmholtz resonator as a well

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Abstract. Noise is a sound that occurs at incorrect time and place so being a nuisance for human activity. Many efforts have done to try to control the noise. One of them using acoustic material called QRD. QRD is a panel consider of wells with different depth to diffuse the reflected sound. The depth of the walls is calculated by DR. Manfred Schroeder formula. In this research, given a new design combination of QRD with resonator, we call QRD-R. The design consist of N7 QRD panel 35 cm x 35 cm using 5 cm x 35 cm Helmholtz resonator as wells’ ground. The purposes of this research are looking for the effect of QRD-R into SPL distribution and attenuation. The result shows there is attenuation in some frequency and there is diffuse effect because of the diffuser.

1. Introduction
Sound that occurs at incorrect time and place is called noise. According to Indonesian Ministerial of Environment Decree number 48 of 1996 [1], noise can cause some health problems for man and also disturb the comfort of environment. Noise can also interfere the communications, cause a physiological until psychological problems [2].

Noise needs to be controlled. The aim of the noise control is a good acoustic environment for outside and inside the room. Some examples of noise control that we know are acoustic barrier installation, the use of acoustic material like reflector, absorber, resonator, and diffuser. Diffuser is one of acoustic material that used to diffuse the sound wave but not reduce the energy [3]. In application, diffuser is used to repair the sound deviations in room like echo that caused noise. Here are the examples of diffusers.

Figure 1. The examples of diffusers.

One of some criteria that can be used as diffuser characteristic assessment is the scattering pattern [4]. Figure 1 shows some type of diffuser, one of them is Quadratic Residue Diffusers (right).
QRD (Quadratic Residue Diffusers) is a panel consider of wells with different depth to diffuse the reflected sound. The depth of the walls (d) is calculated by this equation:

\[ d = (\text{well position})^2 \mod N \] (1)

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

In this paper, a new design of QRD is given by combining the QRD itself with Helmholtz Resonator that hopefully can increase the characteristic of the QRD because of the resonance. The new design is called QRD-R. We will find how QRD-R will impact the SPL distribution and attenuation.

1.1. Well depth calculation

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

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

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).

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

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

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

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 in order from zero to six is 0,1,4,2,2,4,1.

1.2. QRD-R Specification

QRD-R base dimension is 35 cm x 35 cm so every well dimension is 5 cm x 35 cm. For the depth of the well is calculation result times 3 cm. So, in well number order from 0 to 6 the actual depth is 0 cm, 3cm, 12 cm, 6 cm, 6 cm, 12 cm, and 3 cm. The Helmholtz resonator size is shown in the figure 4 (c). The height of every Helmholtz resonator is 12 cm minus the actual depth of each well. The material used for the QRD-R is pine wood.

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 [6].

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 consist of acoustic resistance \((R_A)\), acoustic mass \((M_A)\), and acoustic constant \((C_A)\).

\[ Z = R_a + j \left( \omega M_a - \frac{1}{\omega C_a} \right) \]  (2)

Resonance happens when \( \left( \omega M_a - \frac{1}{\omega C_a} \right) = 0 \), so

\[ f = \frac{1}{2\pi} \sqrt{\frac{1}{M_a C_a}} \]  (3)

\( f \) 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 2008, 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].

4. Methodology

In this part we will see the design of QRD-R. The QRD-R is a 1 Dimension QRD with seven well \((N=7)\). Every well’s ground is made not from a solid material but a hollow material as Helmholtz resonator. In the top surface of the ground, a little hole is given. It is the design of QRD-R.

\[ \text{Figure 3. Equivalent circuit diagram, Helmholtz resonator (left) and RLC circuit (right)} \]

\[ \text{Figure 4. QRD-R Design: (a) The QRD-R; (b) above view; and (c) The Helmholtz Resonator.} \]
See at figure 4, from (a) and (b) we can see that there is a different well depth. That depth is calculated by using equation (1). The solid material of usual QRD is changed by Helmholtz resonator. The design of Helmholtz resonator is shown at figure 4 (c).

5. Simulation
QRD-R design is simulated to learn its harmonic acoustic response. The calculation is using Finite Element Method. QRD-R is put in a closed enclosure filled with air with a speaker. These are the geometry and speaker specification.

5.1. Geometry and speaker specification
This is the geometry that will be simulated.

An enclosure filled with air with a wall as radiation boundary. The space between speaker and sample panel is 1 m. The excitation of the speaker is a mass source and the value is 0.01 kg/m²s.

5.2. Variations
To reach the goals of this paper, the variations are needed. These are the variations.

5.2.1. Speaker and classic barrier. To get the SPL distribution mapping in enclosure with classic barrier.

5.2.2. Speaker and QRD. To get the SPL distribution mapping in enclosure with QRD so can compared with classic barrier.

5.2.3. Speaker and QRD-R. To get the SPL distribution mapping and the attenuation of sound in enclosure after adding the QRD-R.

6. Result
According to equation (3), the resonance frequency of each resonator are 1576.6 Hz for 12 cm height, 1820.56 Hz for 9 cm height, and 229.73 Hz for 6 cm height. These resonators compacted in one diffuser. The results are in the form of SPL distribution map and frequency response graphic from each variation. SPL distribution map is shown in frequency 300 Hz, 900 Hz, 1800 Hz, and 2400 Hz represent the low frequency until medium-high frequency.

Figure 6 shows the SPL distribution map of all variations. The map is a surface viewed from above. The surface is located in the middle of enclosure. A same column is same panel from variation.
Meanwhile a same row is a same frequency. Color contour shows the contour of SPL and its distribution pattern. Max and Min probes are the point where the SPL is maximum and minimum.

Figure 6. The SPL distribution map. It is read from above, a surface in the middle of geometry. Column shows same sample panel (left to right: classic barrier, QRD, QRD-R), row shows same frequency (from up to down 300 Hz, 900 Hz, 1800 Hz, 2400 Hz).

Figure 7. Graphic of frequency response. Each line represents each sample panel from variations. The attenuation can be read easily from this graphic.
7. Discussion
Sound waves produced by the speaker spread all over the room. The speaker is mono directional so the area in the front of the speaker gets a higher energy of sound than the area behind the speaker. We can admit it by looking in figure 6 in classic barrier part (left column). But, in frequency 1800 Hz and 2400 Hz, SPL distribution is more diffuse than 300 Hz and 900 Hz. It prove that sound is tend to be diffuse in high frequency.

Sound wave that reflected by the wall caused the interference phenomena. According to the phase, it can be constructive interference or destructive interference. These things make the difference of SPL distribution pattern in every frequency. That pattern is also caused by the geometry of the room and known as room mode. We can see in figure 6 every row that represent every frequency shows a similar pattern.

In frequency 900 Hz (second row) we can see when the panel is classic barrier the area behind the speaker has a low SPL. But, when the panel is changed into QRD, the refinement is happened. We can see the distribution is more diffuse shown by the decreasing of blue color. The sound produced by speaker diffused by the surfaces of QRD. The waves reflected by the uneven surface of QRD and scattered to all direction. By using QRD-R the sound is diffused more.

In 300 Hz of figure 6 we can see the contour color of QRD-R SPL distribution map more homogeneity than other sample panel. It shows that the sound is really diffused. The holes in the surface of QRD-R increase the area of scattering. So, the incident waves will be reflected into a bigger area. From the value, SPL in enclosure with QRD-R is about 60 – 69 dB. In classic barrier and QRD-R, the SPL is about 70-79 dB (the light green color). The hollows make QRD-R resonance to reduce the energy of sound.

But, in frequency 2400 Hz (last row) installation of QRD-R increase the SPL in front of the panel. It connected with the frequency response of the QRD-R. Move to the graphic in figure 7, we find a fact that in frequency above 2000 Hz (yellow area) SPL at QRD and QRD-R is very high. In 900 Hz and 1800 Hz, QRD-R can attenuate the sound until almost 10 dB compared with classic barrier. It because the resonance frequency of QRD-R. It needed to conduct continuous research to increase and develop the QRD-R.

8. Conclusion
QRD-R increases the diffusion quality of common QRD. And also, the concept of using Helmholtz resonator as a well base makes QRD-R can absorb sound through resonance process. QRD-R can attenuate sound until almost 10 dB compared with classic barrier.

Acknowledgement
This research was supported by Ristek Dikti through ITS LPPM and Acoustic Instrumentation Laboratory, Department of Physics, Institut Teknologi Sepuluh Nopember. The author would like to thank Mr. Dr. Suyatno, M.Sc as the supervisor.

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