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2pAAa4. Designing a quadratic residue diffusor tailored to a violin practice room

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As distinct from a much larger concert hall, the typical practice room directs added acoustic emphasis to small room challenges such as room resonances and unwanted reflections. Although rich reverberation is not easily achieved in a small space, the proposed quadratic residue diffusor seeks to make practice more acoustically comfortable and rewarding. The treatment is designed to diffuse and attenuate the spectral portion of the violin sound that engages the room resonances. When musicians play violin, omni-directional low frequencies are primarily produced in lower elevation of the room, while more directional higher frequencies of interest to the performer are directed more to upper area. In this configuration, the diffusor gives comfortable acoustical conditions for musicians to practice. Based on sound propagation characteristics [7] and formant information of violin[9], this design proposes a moveable acoustic panel-box suitable for a typical musician's home practice room and a small sized recording studio.

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INTRODUCTION

Designing appropriate bowed string instrument practice room-acoustic is trans-disciplinary area, which requires understanding of architectures, physics of sound, and musical knowledge. Schröder, M. R. suggested QRD (Quadratic Residue Diffuser) seeks to find better scattering sound in the space [1], and this paper suggest specially designed QRD for violin practice room. More over, room itself can be considered as an extension of the musical instrument [2]. Among the requirements of ‘good sound room’, frequency response and its reverberation is considered to determining good space. Especially, importance of high-frequency components of reflections are surveyed in A.H.Marshall’s paper ‘Acoustical conditions preferred for ensemble’ [3]

Comparatively, bowed string family rely more on room acoustics than other instruments. Because bowed string mainly uses acoustical vibration to deliver sound. Especially for violin, its high frequency spectral information (2kHz~10kHz) is easy to be combined with room resonate in small-sized practice room / recording place. These days, polyurethane sound absorber is widely used to attenuate reverberant practice room, but it absorb too much higher frequencies and make practice room acoustic too dull. (Attenuate too much high frequency above 2kHz and over) Therefore, appropriate diffusing and absorbing peak frequencies would help to create comforting practice room / recording space for strings.

In this paper, Quadratic Residue Diffuser has designed to spread and scatter spectral characteristics of violin, which widely played among string instrument in terms of numbers. In this paper, two set of QRD has built for higher frequency (project frequency 2500Hz), and two set of QRD has built for lower frequency (project frequency 550Hz). So that the practicing / recording musician has more sense of playing in a larger space, by hearing more elements of their own tone. Frequency variability may happen based on the instrument, the performance, tuning, the key and range of any given piece of music. However, above mentioned two frequency bands will be an useful ‘targets’ to diffuse and attenuate for better performance in small size room / recording space.

METHODOLOGY

QRD (Quadratic Residue Diffuser) has been proved to effective diffuser for designed frequency area, it also verified in 2-D digital wave guide mesh system by Lee et al. [4] QRD originally designed by M.R. Schroeder to support sound propagation in median-plain by adding diffuser on ceiling, but it is widely used in wall to prevent unwanted room resonances [5]. In this paper, violin’s character was investigated and applied to QRD specially designed by its characteristics.

From the book “Bowed Strings. The Science of String Instruments” by Rossing, Thomas D. [6], 550Hz Bending Mode and 2kHz~3kHz Bridge Hill Mode are dominant frequency area which easily relate with room mode and its resonances. For typical sit and stand position, violin-QRD size has determined with 80cm width, and 100cm height. According to ‘The Sound of the Orchestra’ by Meyer J.[7], lower frequency is more omni-to lower area and higher frequency direct more upper area. Therefore, QRD has built with project frequency of 550Hz for below section and 2500Hz for upper section. 18mm, and 9mm of birch plywood has used for violin-QRD production.

Additionally, on the back of the diffuser, 25mm of absorbing polyurethane foam has inserted. [Figure 3] Four wheels were installed on the bottom the diffuser. If the space is too much reverberant, more attenuation can be achieved by rotating QRD on the other side. The other function of the rear panel of upper set is preventing unwanted reflection from the wall. Therefore upper set has about 4cm of space between wall and diffuser [Figure 4]. In case of both absorbing and diffusing required half and half, one set can be used for diffusing and the other may be used for absorbing side [Figure 4].

Measurement proceeded at a small room 360cm(w) x 832cm(d) x 269cm(h) at the position of 1/3 of the depth. Measurement software was ‘FuzzMeasure®’ and sound equipment are Genelec 8040A, Focal CMS Subwoofer, and DPA 2006 omni-directional microphone, and DPA 5100 5.1ch surround microphone. Violin-QRD’s frequency response has measured by sine sweep for 1sec(1000ms), full range (20Hz~20kHz). Its detailed character analyzed again with Fast Fourier Transform in Matlab by analyzing 2min’ of recording violin piece on the diffuser wall and plaster wall. (software - Protools 10, audio interface - RME babyface, Recording at 48kHz, 24Bit) Violinist was
requested to play as same as possible between the playing four times of same piece – J.S. Bach partita no.2 IV. Gigue d-minor.

**FIGURE 1.** An overlay of five microphone positions from “Bowed Strings. The Science of String Instruments” by Rossing, Thomas D. [6] 550Hz area Bending Mode and 2kHz~3kHz Bridge Hill Mode illustrated on the graph

Determined QRD order was 7. As mentioned above, Project frequency $f_0$ was 550Hz, 2500Hz at the temperature of 22°C. By the QRD Calculations [1], Cell width was 8.6 cm and its effective frequencies area is 412.5Hz~2007.3Hz for below diffuser, and 1875Hz~9124.1Hz for upper diffuser.

**TABLE 1.** Designed QRD for spectral characteristics of violin

<table>
<thead>
<tr>
<th>Project Frequency</th>
<th>550 Hz</th>
<th>2500 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell width</td>
<td>8.6 (cm)</td>
<td>1.9 (cm)</td>
</tr>
<tr>
<td>Effective frequency low</td>
<td>412.5 (Hz)</td>
<td>1875 (Hz)</td>
</tr>
<tr>
<td>Effective frequency high</td>
<td>2007.3 (Hz)</td>
<td>9124.1 (Hz)</td>
</tr>
</tbody>
</table>

Considering the effective range, violin characteristics of frequency response and violin-QRD effective frequency range are overlapped. According to Nam’s Master thesis [8], violin’s main spectral and amplitude characters are mostly included in the area (412.5Hz~9124Hz). Figure 2. shows percentile sound level $L_1$ of three different violin pieces.

**FIGURE 2.** Violin characteristics of frequency response and violin-QRD effective frequency range overlapped. Percentile sound level $L_1$ of three different violin pieces from Myoung W. Nam’s Master’s thesis [8]
FIGURE 3. QRD tailored to violin - below for 550Hz, upper for 2.5kHz (Front side-diffuser / Rear side-absorber)

FIGURE 4. violin-QRD set up in a room - one side absorber the other side diffuser configuration
RESULTS

In [Figure 6], frequency response by sine sweep has displayed. Blue line is plaster wall and red line is violin-QRD wall. Noticeable frequency smoothing has shown from 1kHz to 10kHz area. Especially when microphone is 30cm and 40cm away from the wall, bumping spectral frequency has scattered well out. Since this measurement was proceed in a room, this result shows the violin-QRD may apply to other typical small room situation.

Finally, violinist's recording [Figure 7] has analyzed. Professional violinist was asked to play J.S. Bach partita no.2 IV. Violinist played Gigue d-minor for several times, on the diffuser wall and the plaster wall. Each recording has recorded with two DPA 2600 mic and one DPA5100 mic, which has 5.1 surround microphone one it. After recorded on Protools 10 software, the analyzed data has shown different character for different setup (diffuser and plaster wall). [Figure 8] shows Fast Fourier Transform result of the recording that 2.5kHz area peak (notes of the piece and violin formant) and 550Hz area are attenuated by violin-QRD spreading those frequencies. Also, other bumping reverberation between notes and harmonics are smooth out-suspected as reverberation tails—which is spectral characters of typical large concert hall. In [Figure 9], smoothing reverberation and sub-harmonic tones between peaks are observed at over 800Hz area. This seems to related EDT (early decay time), T20 and T30 of non-tonal area, the area need further study.

By observing sine-sweep spectral response, and violin recording analyzed data, QRD tailored to violin proved to appropriate for scattering and attenuate desired frequency areas of 550Hz and 2.5kHz. So the violinist may have comfortable acoustical experience, as he/she feels at well-designed large reverberant hall at least in spectral perspective.
FIGURE 6. Measured result of frequency response of ‘empty wall (plaster)’ and ‘diffuser wall’ by sine sweep (Upper: 30cm away, below: 40cm away / Software used FuzzMeasure®, mic-DPA 2006)

FIGURE 7. Recording violin piece ‘J.S. Bach partita no.2 IV. Gigue’ on the diffuser wall (software - Protocols 10, audio interface - RME Babyface, mic-DPA 2006, DPA 5100, Recorded at 48kHz, 24Bit)
FIGURE 8. Fast Fourier Transform result from the recording violin piece 'J.S. Bach partita no.2 IV. Gigue' on the diffuser wall and plaster wall (software - Protools 10, audio interface - RME Babyface, mic-DPA 5100, Recorded at 48kHz, 24Bit)

FIGURE 9. Smoothing reverberation and sub-harmonic tones between peaks 800Hz~5kHz cut
REFERENCES


