Comparison Between Generic Quadratic Residue Diffusors and RPG's Modffusor

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TABLE OF CONTENTS

0 INTRODUCTION

In 1983, RPG Diffusor Systems, Inc. introduced the first commercial sound diffusor that offered uniform scattering over a designable bandwidth. The QRD® has has now been used in thousands of projects in a wide range of venues. As with any technology, research and experimentation lead to advances. The QRD® is a reflection phase grating formed from the periodic repetition of a base shape, consisting of a series of wells of depth based on the quadratic residue sequence, separated by dividers. While periodicity is the basis of the QRD®, it is also one of its limitations, because periodicity causes lobing in specific diffraction directions. To minimize this lobing, which compromises the uniformity of the polar response, RPG developed the Modffusor™. By contrast to the QRD®, the Modffusor™ is formed from an aperiodic array of a single, asymmetric, optimized base shape. The optimization offers better performance than a low-prime, number theoretic diffusor and the aperiodic modulation minimizes lobing non-uniformity caused by periodicity. Thus, the Modffusor™ offers the next generation of high performance reflection phase gratings. Due to the success of RPG's QRD®, older traditional absorption and noise control manufacturers has attempted to copy it. Specifiers should be made aware that because these manufacturers are not authoritative in sound scattering technology they are simply copying technology that is over 23 years old. RPG is internationally recognized as the authority in sound diffusor design and optimization and in 2001, RPG's President/Founder, Dr. Peter D'Antonio and Prof. Trevor Cox published the industry's most comprehensive reference text describing the current state of knowledge on sound absorbing and sound diffusing surfaces, entitled "Sound Absorbers and Diffusers: Theory, Design and Application" Spon Press. We respectfully suggest that specifiers reject outdated QRD technology and consider the advanced Modffusor design patented by RPG to overcome all of the shortcomings of the traditional QRD. In this white paper we will illustrate the dramatic advantage

Figure 1. Left- RPG's advanced patented QRD®, which is called a Modffusor, because it's design is based on a modulated, optimized diffusor as opposed to the older number theory approach introduced in 1983. Right: Traditional number theoretic QRD.

0.1 Samples

In Figure 1 we show RPG's advanced Modffusor on the left in a white birch finish and the traditional QRD in a stained oak finish.

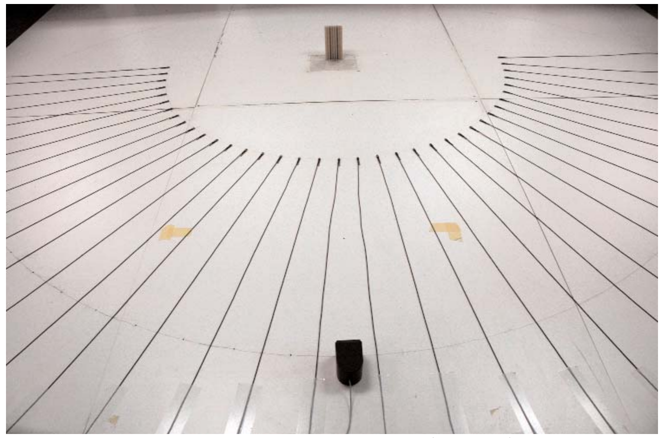

Figure 2. RPG 2D Goniometer with speaker at normal incidence, 37 receiving microphones at 5 degree intervals and a test sample of a QRD. Speaker radius is 2 m and microphone radius is 1 m.

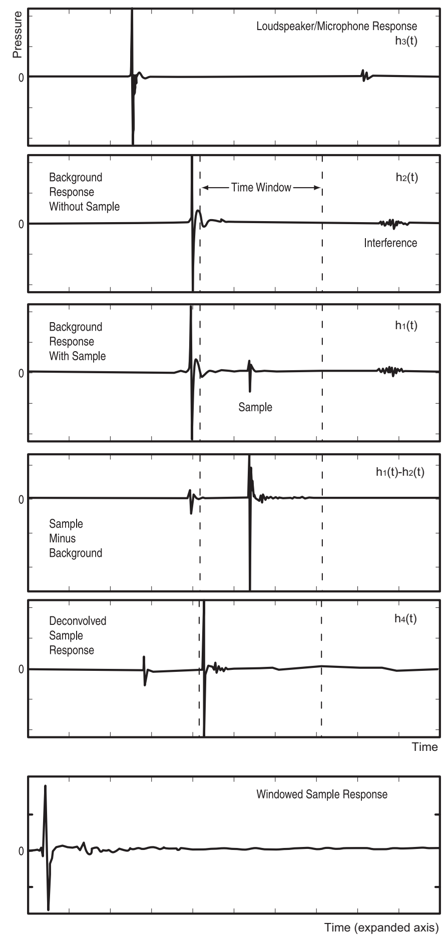

Figure 3. Data reduction process to extract the scattered impulse response from a test sample at a given observation angle.

The Modffusor measures 23 5/8” x 23 5/8” x 7 7/8” and the QRD measures 23 5/8” x 23 5/8” x 9 1/8”. The asymmetric Modffusor contains 7 full-width wells and 2 zero-depth half-width end wells. The Modffusor is no longer bound to contain a prime number of wells as in the number theoretic QRD which contains 6 full-width wells and two zero-depth, half-width end wells. These end wells are RPG’s patented approach. You will notice that the optimization and aperiodic modulation of the asymmetric Modffusor permits the unit to be 14% shallower than the QRD, with as will be apparent superior performance. In order to illustrate this improved performance, we will review the measurement procedure utilized.

1 MEASUREMENT AND DATA REDUCTION

In 1990 RPG initiated the DIrectional Scattering Coefficient (DISC) project to evaluate the directional scattering characteristics of diffusing and absorbing surfaces. The measurements were carried out with a new boundary layer goniometer, shown in Figure 2, in which 37 sequential impulse response measurements were made, using 37 fixed pressure zone microphones and an MLS excitation signal under computer control. Figure 3 illustrates the sequence of events in determining the scattered impulse response at a particular observation angle, for a given angle of incidence. To obtain the impulse response of a sample under test, it is necessary to de-convolve the loudspeaker-microphone response at each scattering angle, $h_3(t)$. It is also necessary to minimize any room interference and reflections from microphone supports and wires within the time window of interest. To obtain the "Loudspeaker/Microphone Response" (top panel in Fig. 3) at each scattering angle, the loudspeaker is placed at the sample position and rotated so its on-axis response is coincident with the on-axis response of each microphone for each angle.

The loudspeaker is then placed in its normal source position, without any sample present, and the "Background Response Without Sample", $h_2(t)$, at each angle is automatically measured via computer control by emitting 37 impulses and sequentially switching each microphone on. A vertical dotted line representing the "Time Window" of 10 ms used to isolate the reflections is also shown. The sample under test is then placed in position and the scattered sound is measured, obtaining the "Background Response With Sample", $h_1(t)$, in Figure 3.

Data are collected at 5 intervals. Higher resolution, for example 2.5, is possible by combining another data set with the sample rotated by 2.5 . The measurement system selects a microphone, emits a selected maximum length sequence stimulus, records the data, selects the next microphone position, etc. Since the microphones are stationary and the measurement process is rapid, the respective background response can be subtracted from each microphone position, prior to de-convolution. This is illustrated as "Sample Minus Background" in Figure 3. The direct sound is significantly decreased and is not providing interference in the time window with the scattered sound. The room interference is also decreased. The speaker/microphone response can now be de-convolved as illustrated in "De-convolved Sample Response", $h_4(t)$, where $h_4(t)$ is calculated using Eq. 1, where FT and IFT are the forward and inverse Fourier transforms. The data within the Time Window is gated to isolate the "Windowed Sample Response".

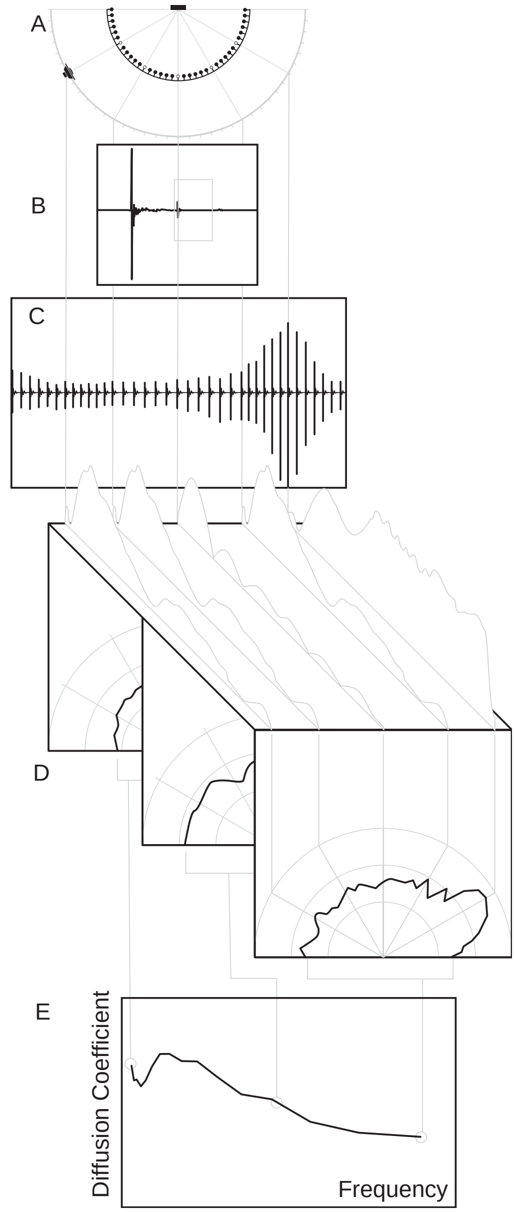

Figure 4. Summary of data processing technique from a flat reflector at -60^0 incidence.

$$h_4(t) = IFT\left\{\frac{FT\left[h_1(t)-h_2(t)\right]}{FT\left[h_3(t)\right]}\right\} \qquad (1)$$

The data are further post processed to provide frequency responses, polar responses and finally diffusion coefficients, as shown in Figure 4. The top of Figure 4A, shows the 2D boundary measurement geometry with the exciting loudspeaker at an angle of incidence of -60^0, with respect to the normal. Also shown are the 37 receiving microphones. A flat non-absorbing sample is being measured. Below that, Figure 4B, the impulse response at 0 is shown, with the scattered data outlined in a box, corresponding to the time window in Figure 3. The scattered data are windowed for all of the angles of observation, of which five are highlighted at -60, -30, 0, 30 and 60^0 and concatenated in Figure 4C in the form of a temporal angular impulse response. A Fourier Transform is then applied to each part of the impulse response to get the frequency responses, Figure 4D. Five of the 37 frequency responses are only shown for clarity. The frequency response energy is summed over one third octave bands and three of the polar responses are shown in Figure 4D. The visible polar response at high frequency is narrow and directed in the specular direction of +60 as would be expected. The polar responses can then be further processed to give a diffusion coefficient, which is plotted versus frequency to obtain the diffusion response, Figure 4E. As the frequency increases, one can see a drop in the diffusion coefficient, as the width of the panel become increasingly large compared to the wavelength.

The DISC project evolved into an AES information document entitled AES-4id-2001. This information document is being incorporated into the ISO 17497-1:2004 for the random incidence scattering coefficient.

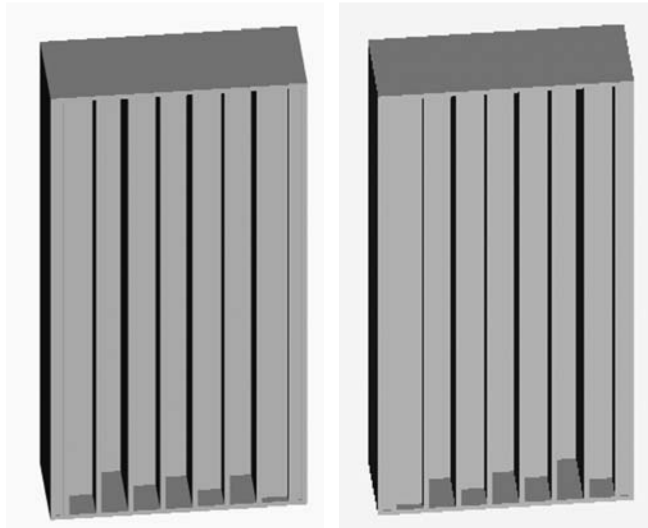

Figure 6: (Left) Binary 0 Unit. (Right) Binary 1 Unit is a mirror image of the binary 0 unit.

2 RESULTS

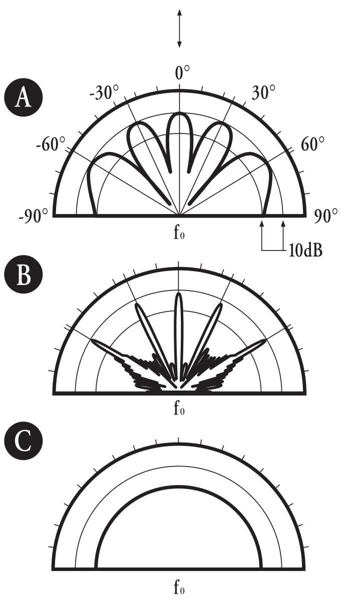

Figure 5. (A) Polar response of a prime 7 traditional QRD. Old paradigm was for equal energy in the diffraction directions. (B) Focusing of energy into the diffraction directions when 25 units are periodically repeated. (C) New uniform scattering paradigm used to design the Modffusor allows the performance of an aperiodicaly modulated array to be similar to the performance of a single optimized unit.

Quadratic Residue Diffusors (QRD®) owe their diffusing ability to the phenomenon of diffraction from a periodic reflection phase grating. The product of the number and width of the wells defines the diffraction directions and the energy in these directions is equal due to the fact that the quadratic residue well depth sequence has a flat power spectrum.   To cover wide areas, the QRD® is repeated. This periodicity decreases uniformity by focusing the energy in the diffraction directions (B), preventing uniform diffusion (C) from being achieved, Figure 5.

To solve this problem, RPG patented a concept called Aperiodic Modulation of a Single Asymmetric Base Shape, in which a single, optimized, asymmetric, base shape (“0” Unit), Figure 6, is modulated by simply flipping the base unit 180^0 (forming “1” Unit) according to the prescrip-

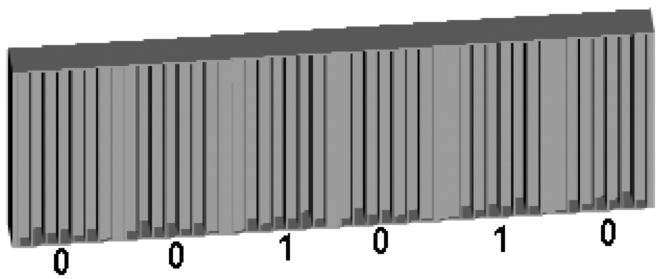

Figure 7. Aperiodic modulation of a single asymmetric shape, which consists of binary 0 units and flipped binary 1 units. Using appropriate optimal binary sequences, an infinite array can be created without introducing any of the problems associated with periodicity.

tion of an optimal binary sequence with good aperiodic autocorrelation, as shown in the aperiodic array in Figure 7. The base shape, consisting of 7 full wells and two zero-depth half wells on either end, is optimized using RPG’s proprietary Shape Optimizer™ software. Using aperiodic modulation, the performance of the single optimal base shape can be preserved, while covering an infinite area. The patented half wells provide seamless tiling and the appearance of pseudo-periodicity and pseudo-symmetry which is aesthetically pleasing.

By measuring the scattering of a traditional QRD and Modffusor according to AES-4id-2001, we can now illustrate the dramatic improvement that optimization and modulation provide. In Figure 8, we show a Diffusion Coefficient comparison between a traditional QRD and the Modffusor. It is apparent that in addition to the higher diffusion coefficient of the Modffusor, one is ideal, the low frequency performance is extended as well. Equally important, the Modffusor is 14% shallower than the QRD, thus requiring less surface depth, an important constraint.

A flat panel response of comparable size is also shown to indicate the Modffusor's better low frequency diffusion, as indicated by the onset of diffusion.

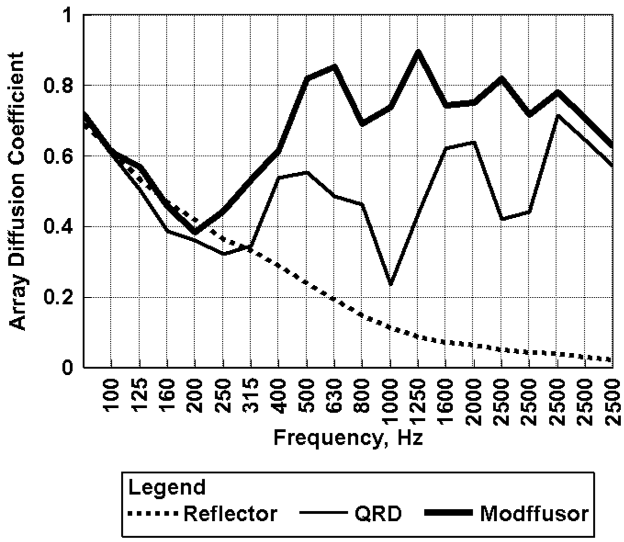

Figure 8. Diffusion coefficient comparison between a traditional QRD and the Modffusor, reveals significant performance improvement, due to the reduction of periodic lobing. A flat panel response of comparable size is also shown to indicate the Modffusor's better low frequency diffusion, as indicated by the onset of diffusion.

3 CONCLUSION

It is clear from a comparison between the diffusion coefficients of a traditional generic QRD and the new and improved Modffusor, that the diffusion response for the Modffusor is superior and extends to lower frequency, with a 14% decrease in panel depth. The aperiodic modulation of the optimized base shape does not distract from the appearance of the traditional QRD, due to the fact that the zero-depth, half-width end wells provide a pattern for the eye to focus on. In addition, large arrays can be seamlessly generated using a full width, zero-depth well joining adjacent units.