Technical Bulletin on the Evaluation of the Kinetics Tuned Absorber/Diffuser Panel

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This technical bulletin describes the design theory behind a hybrid diffusor-absorber, called a diffsorber, describes RPG's patented application of this theory and evaluates a product called the Kinetics Tuned Absorber/Diffuser Panel (KTAP), developed by Kinetics Noise Control, in an attempt to circumvent this patent.

0 INTRODUCTION

A diffuser redirects the reflected wavefront. While this can be achieved by shaping a surface, it can also be achieved by changing the impedance of the surface. Indeed, the well known reflection phase grating diffuser, based on number theoretic sequences, is often interpreted as a variable impedance surface. In the hybrid diffsorber, variable impedance is achieved by patches of absorption and reflection, giving pressure reflection coefficients nominally of 0 and 1, respectively. By changing the number of hard and soft patches on the surface, it is possible to control the absorption coefficient. By changing the ordering of the patches, it is possible to control how the reflected sound is distributed. If a periodic arrangement of patches is used, then the reflected sound will get concentrated in particular directions due to spatial aliasing; these are then grating lobes. If an optimal number theory sequence is used to determine the patch arrangement, then the scattering will be maximally uniform. Consequently, choice of an optimal number theory sequence is crucial to providing uniform scattering. RPG has described in U.S. Patent No. 5,817,992 effective planar two-dimensional binary amplitude sequences, forming a commercial product called a binary amplitude diffsorber or BAD™ panel. Unlike the reflection phase grating diffuser, these cannot be designed for minimum absorption. These surfaces are hybrids, somewhere between pure absorbers and non-absorbing diffusers. Partial absorption is inherent in the design, and any reflected sound is dispersed.

We begin by describing how to evaluate the quality of a suitable number theory sequence to maximize the dispersion generated, so that we can compare the performance of the KTAP.

1 ONE-DIMENSIONAL NUMBER THEORY SEQUENCES

To gauge the quality of a number sequence for a hybrid surface, the autocorrelation function can be examined. This is because the autocorrelation function directly relates to the scattering performance of the surface. If the autocorrelation function is a delta function, then the power spectrum, which reflects the uniformity of scattering, will be uniform.

Let's look at some simple examples of the autocorrelation and power spectrum of unipolar (0, 1) and bipolar (-1, +1) sequences.

The reflection factors for the hybrid surface are 0 (absorption) or 1 (reflection), consequently the number sequence used should have optimal autocorrelation properties for 0s and 1s, which means a suitable unipolar sequence is required. Most pseudorandom binary sequences, on the other hand, have autocorrelation properties designed with a bipolar sequence composed of +1s and -1s. The autocorrelation side lobe performance of a unipolar and bipolar sequence can be very different. Figure 1 demon-

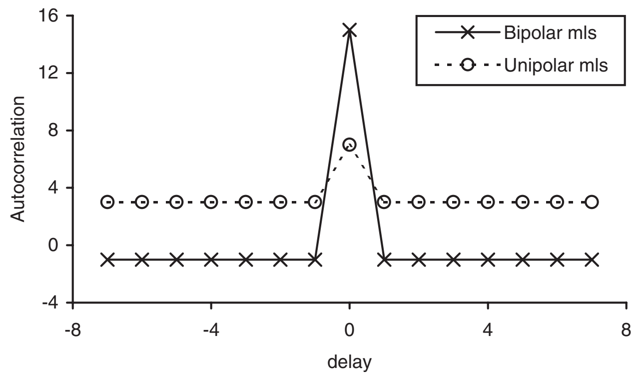

Figure 1. Autocorrelation function for a bipolar (+1 and -1) and unipolar (+1 and 0) MLS sequences. The former is like a phase grating diffuser, the latter is like a hybrid diffsorber.

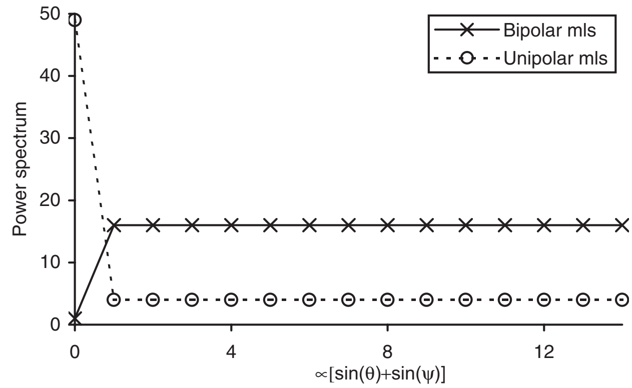

Figure 2. Comparison of power spectra for the reflection coefficients of surfaces formed from bipolar and unipolar MLS sequences.

strates this for a maximum length sequence of length 15. When a sequence can be bipolar (positive and negative), the autocorrelation function side lobes, on either side of zero delay, include cancelling effects, which enables a low side lobe energy to be created as desired. When the sequence is unipolar, no cancellation can occur, and the autocorrelation side lobe levels are higher. Consequently, it would be anticipated that the scattering performance would be worse for a unipolar sequence. The consequence of no cancellation is that the d.c. component in the power spectrum, i.e. the specular reflection, is large, as shown in Figure 2. This means that the energy in the specular reflection direction, when $\sin(\theta)+\sin(\psi)=0$, will be attenuated less for a unipolar surface in comparison to a bipolar surface.

In a bipolar maximum length sequence, the mean value of the reflection factors is close to zero, and consequently the d.c. value of its power spectrum is close to zero, Figure 2. This means that suppression of the zeroth order lobe in the polar response, when $[\sin(\theta)+\sin(\psi)]=0$ occurs - see Figure 1. With a unipolar maximum length sequence, a hybrid absorber-diffuser is being constructed. The mean value of the reflection factors is no longer close to zero. Indeed the d.c. value is actually higher than other spectrum values, and consequently the zeroth order lobe is significantly greater than other lobes. Figure 2 illustrates this by comparing the power spectra of a unipolar and bipolar maximum length sequence. Figure 3 shows the polar response for a diffuser constructed from bipolar and unipolar maximum length sequences. This is evidence that the planar hybrid surfaces will have a significant specular energy lobe, with this zeroth order lobe being about 10log10(N) times larger than the other lobe energies, where N is the size of the maximum length sequence.

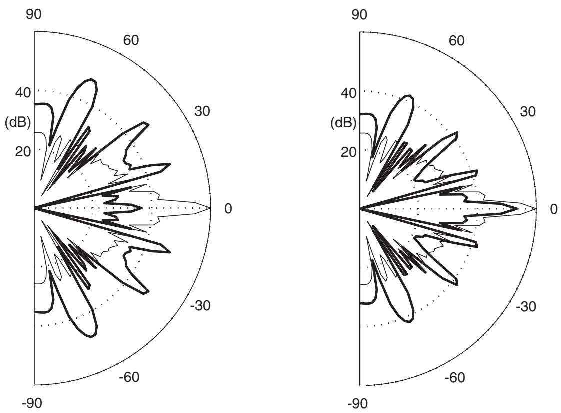

Figure 3. Scattering from diffusers constructed using bipolar and unipolar MLS sequences. Thin lines are for flat reflectors and thick lines are for bipolar (left) and unipolar (right) diffusers.

The specular reflection lobe will be attenuated by about 6dB compared to a plane hard surface (as expected for a surface which is 50% absorptive by surface area). The scattering lobes are not even for the hybrid surface, but the scattering in the specular energy is reduced.

When the open area of the panel is about 50% then the maximum length sequence is an optimal choice. The performance of the maximum length sequence when composed of unipolar elements is worse than when it is bipolar as shown above, but the maximum length sequence will still be the best possible sequence achievable; there are no better unipolar sequences, although there are some which are just as good.

To summarize, a sequence that has a good autocorrelation function will have uniform scattering and we can use this criterion as a measure of the quality of a hybrid diffuser.

2 TWO-DIMENSIONAL SEQUENCES

So far we have used 1D sequences to explain the relevance of the autocorrelation function in evaluating the performance of a diffsorber. In practice, 2D or omnidirectionally scattering diffsorbers are often preferable. An efficient method to design 2D diffsorbers, described in the RPG patent cited above, is to use the Chinese Remainder Theorem, which folds a 1D sequence into a 2D sequence with similar autocorrelation properties. The Chinese

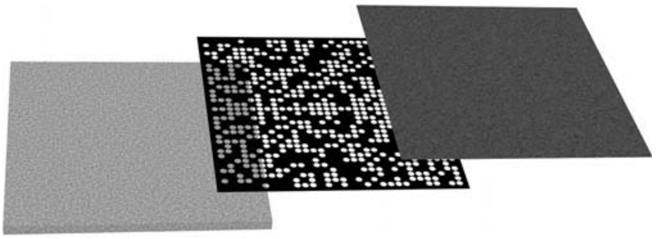

Figure 4. Construction of a hybrid surface, left porous absorber, middle binary amplitude template and right fabric. The fabric is only necessary if it is desired to cover the pattern.

Remainder theorem is a process that wraps a 1D sequence into a 2D array and yet preserves the good autocorrelation and Fourier properties of the 1D sequence.

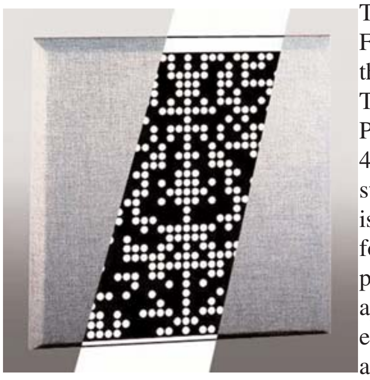

Figure 5. Cutaway view of the RPG BAD panel.

The template shown in Figure 4 was formed using the Chinese Remainder Theorem, as described in Patent No. 5,817,992. Figure 4 and 5 show a typical construction. A fiberglass panel is faced with a complex perforated template, and the panel is fabric wrapped for appearance. The white patches on the template are holes, and the black patches hard reflecting surfaces.

Figure 6 shows the random incidence absorption coefficient for hybrid surfaces with various thicknesses of fiberglass, compared to the fiberglass alone. The diaphragmatic action and additional vibrating air mass within the holes of the template causes the absorption curve to shift down in frequency, thus generating additional low to mid frequency

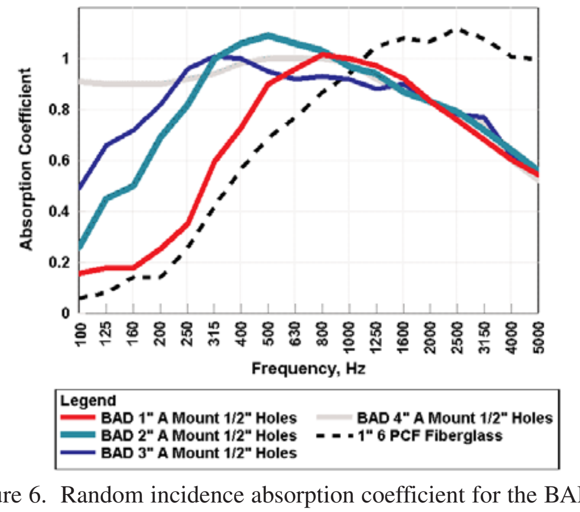

Figure 6. Random incidence absorption coefficient for the BAD panel with 1, 2, 3 and 4” fiberglass rear panels, in an A mount, compared to 1” 6 pcf fiberglass.

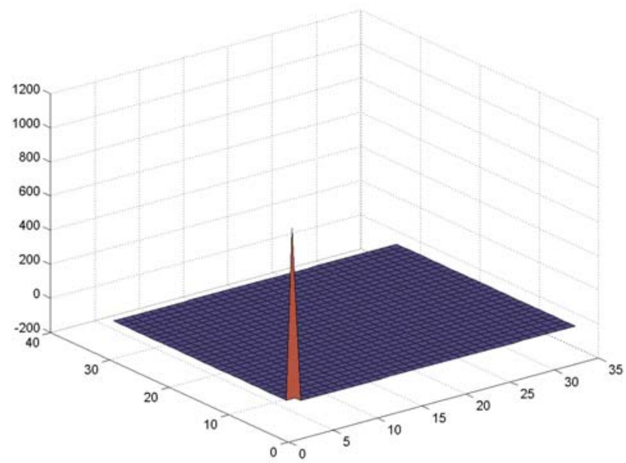

Figure 7. Autocorrelation of a 31x33 2D bipolar MLS sequence. Now instead of the 1-dimensional autocorrelation plot of Figure 1, we have a surface plot with a delta function at the origin. Only one quadrant is shown, with an origin peak value of 1023 (31x33) and side lobes at -1.

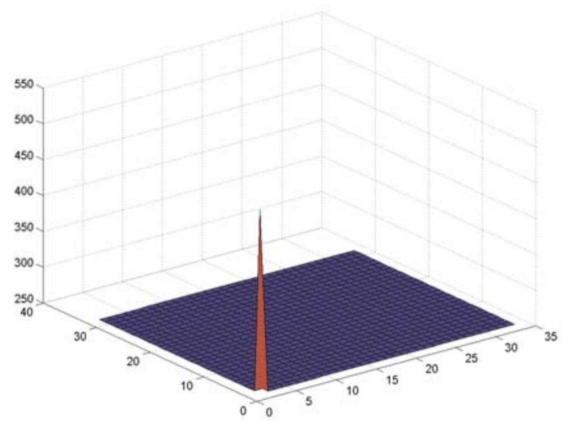

Figure 8. Autocorrelation of the 31x33 unipolar RPG BAD panel. Note a rise in the side band energy due to the lack of cancelation available in the bipolar sequence, as we shown in Figure 1 for a simple 1D sequence. Origin peak is 511 and uniform side band values are 255.

absorption. At high frequency, the non-perforated parts of the template shield the fiberglass and preventing absorption happening in some parts of the fiberglass, resulting in a reduction in the absorption coefficient. It is at these high frequencies, where the absorption is reduced, that the surface generates significant amounts of diffuse reflections.

To accomplish mid to high frequency dispersion a 31x33 two dimensional array of absorptive or reflective areas is used. The reflective areas map to the 1 bit and the absorptive areas map to the 0 bit in a binary pseudorandom number sequence. The distribution of these binary elements is based on an optimal binary sequence with a flat power spectrum as this maximizes dispersion. Hybrid surfaces extend the acoustical performance of traditional fabric wrapped absorbers, and allow wide area coverage without excessive deadening at mid to high frequencies. The surface is used in facilities that need mid-band absorption control and high frequency diffusion (ambiance). Furthermore, the acoustic function can be hidden by fabric, for example, which can lessen the conflict between visual aesthetics and acoustic requirements. Alternatively, many architects have expressed interest in seeing the template, due to its unique appearance and the fact that it offers an alternative to the traditional periodic perforated metal patterns.

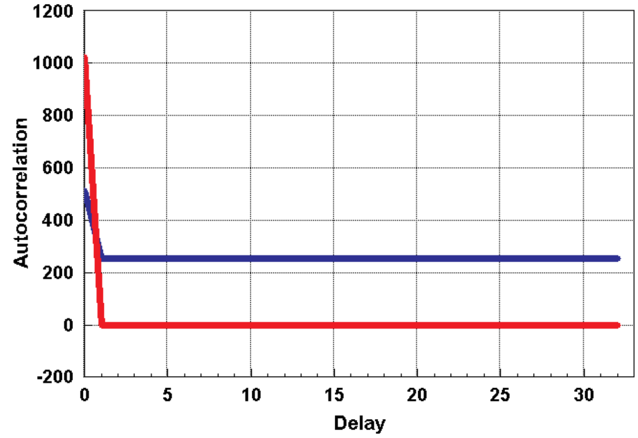

Figure 9. 33 element 1D slices of the autocorrelations shown in Figure 7 and 8, as a comparison to Figure 1. Only positive delays are shown.

0	0	0	1	1	0	1	0	0	1	1	1	0	1	0	1	1	1	0	1	0	0	1	0	1	0	1	0	0	1
1	1	0	1	0	0	1	1	1	1	1	0	1	0	1	0	0	1	0	1	0	1	1	0	1	0	1	1	0	1
0	1	0	1	1	1	0	1	0	1	1	0	1	0	1	1	0	0	1	0	1	0	1	1	0	1	0	1	0	1
0	0	1	1	0	1	0	1	0	0	0	1	1	1	0	1	1	0	1	1	1	0	1	0	1	1	1	1	1	0
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1	1	1	0	0	1	1	1	0	1	1	0	0	1	1	1	0	1	0	1	1	0	1	1	1	1	0	1	0	1
0	1	0	1	1	1	0	0	1	1	0	1	1	0	0	1	1	0	0	1	1	1	1	0	0	0	1	0	1	0

Figure 10. Sequence used in the Kinetics Tuned Absorber/Diffuser Panel.

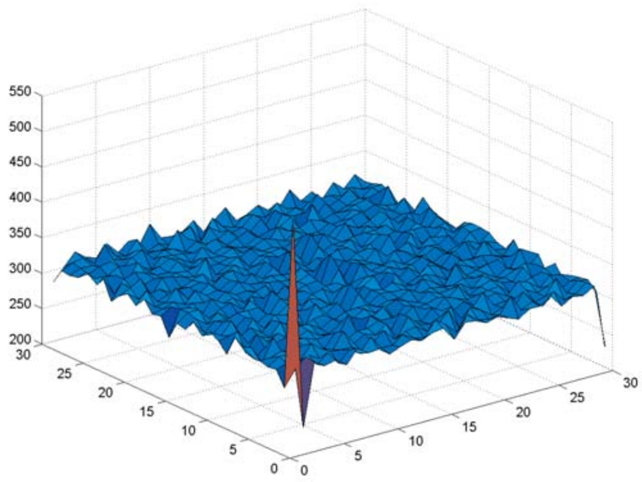

Figure 11. Autocorrelation for the 30 x 30 element KTAP. Note the non-uniform side band, bifurcated origin peak and long delay anomaly.

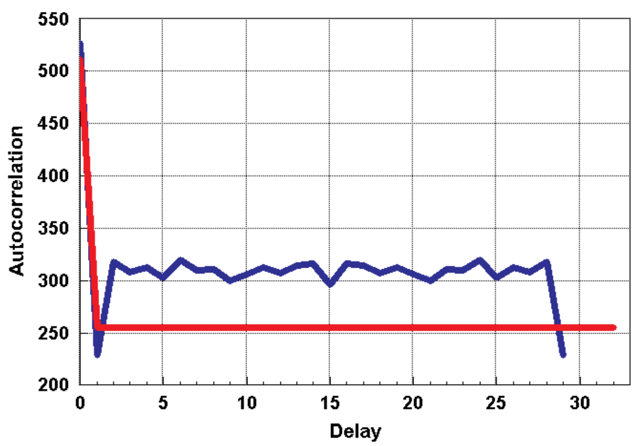

Figure 12. Comparison of the RPG BAD panel with uniform side band energy and the KTAP panel, with non-uniform raised side band energy and long delay anomaly

The autocorrelation for a 2D diffsorber is represented by a surface plot, since the scattering will be omnidirectional, rather than in a single plane. In Figure 7, we show one quadrant (all others are identical) of the autocorrelation for a bipolar maximum length sequence, which has a perfect autocorrelation, with an origin peak at 1023 (31 x 33) and uniform side bands at -1. By comparison, the autocorrelation for the RPG unipolar BAD panel is shown in Figure 8. The origin peak is now reduced to 511 with uniform side bands raised to 255. The differences may be more easily seen in a comparison of the 1D 33 element slices for the bipolar and unipolar (BAD panel) sequences, shown in Figure 9.

3 EVALUATION OF KTAP

With this background in mind, we can now use the autocorrelation function to evaluate the KTAP product, by essentially evaluating the sequence chosen. Kinetics describes their sequence as follows: "A design process is utilized to optimize the randomness of the hole pattern in the laminate (template) while maintaining the desired overall open versus reflective area in the panel surface". The 2D "random" sequence chosen is shown in Figure 10. In Figure 11, we show the autocorrelation for the KTAP product. Note the anomaly at the origin and long delay, as well as the very irregular side band energy, which is also raised significantly compared to the optimal BAD MLS sequence, which has a flat power spectrum. The superior performance of the BAD panel may more easily be seen in the one dimensional autocorrelations in Figure 12, in which we compare a 30 element KTAP slice with a 33 element RPG BAD panel slice. Note the irregularity at the origin and the raised side band energy of the KTAP panel, compared to the uniform performance of the RPG BAD panel. The non-uniform sideband energy will mean that the non-zero order lobes produced by a periodic arrangement of the KTAP panel will not all have the same energy; hence it deviates from the normal design criteria for periodic diffusers. The raised levels of the autocorrelation sideband energy will result in grating lobes of higher energy than produced by the BAD panel.

4 CONCLUSION

We have provided a theoretical background to understand the importance of the autocorrelation in evaluating a potential 1D or 2D sequence for designing a unipolar binary amplitude diffsorber. We have presented the autocorrelation for the patented RPG BAD panel and the Kinetics Tuned Absorber/Diffuser Panel, which is being offered to the market place as an equal substitute for the BAD panel. The data clearly indicate that the Kinetics panel exhibits poorer scattering performance, as demonstrated by its less delta-like autocorrelation. The reason for this poorer performance is the choice of a "random" sequence, which is sub-optimal. In conclusion, while the Kinetics Tuned Absorber Panel is fabricated to look similar to and purported to be equivalent to the RPG BAD panel, contractors, architects, acousticians and clients should be aware of the fact that it does not offer equivalent acoustical performance.