The Misunderstanding of Acoustic Diffusion and Testing

Where we've been, where we are and where we're going

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Preface

Of all the acoustic test data supplied by manufacturers, laboratories and taught in our universities, the data representing acoustic diffusion is the least understood, the least reliable and the most disturbing with regards to providing any really relevant data. This may sound a bit startling to many but, as you read this, we have been suffering, for over a decade, under the assumption that the limited information we receive in both the current standards for scattering and diffusion testing is accurate. Frankly, it's not.

There are currently (2) ISO standards for testing diffusers, ISO 17487-1 (scattering test) and ISO 17497-2 (diffusion test, formerly AES 4-id). The output data for these tests are represented as coefficients and attempt to display the complex nature of a diffuser as a single or dual graph. The -1 test has both scattering and absorption curves while the -2 test has both diffusion (polar response) and correlated scattering (derived random incidence) curves.

The problems lie in both the way the tests are generally conducted and in the misinformation as to what the data is supposed to represent as diffusion. We like to call it the confusion of diffusion.

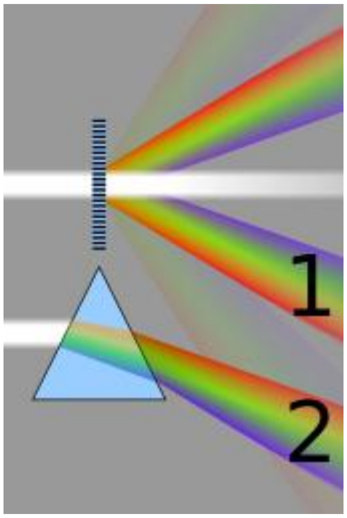
What is Diffusion?

Inasmuch as this paper is designed for both the professional acoustician and other interested parties, a short explanation of diffusion and its properties is included herein.

While many believe they understand what a diffuser does, the manufacturing side of the acoustics industry has muddied the waters much over the years. The first known product represented as a diffuser (to our knowledge) was based on Dr. Manfred Schroeder's work in 1975-76 in the development of phase grating diffusers, commonly known as quadratic residue diffusers or QRD for short.

There is no question that Dr. Schroeder knew what he was talking about when he created these devices. In fact, his use of the words "phase-grating" is most important to this conversation and to understanding what diffusion is.

Diffusion is the process of an acoustic wave hitting a surface and being manipulated such that the return waves coming off of the surface are broken up into mixed *phase* waveforms. The opposite of a diffuse wave is a specular reflection or, a reflection that has a single phase response. This concept is more easily explained by using something we all deal with every day, that is, light.



White light is a diffuse light. It is made up of many different colors, or single phase/frequency light waves. This is best represented when a source light is put through a prism (# 2) which acts as a refractor separating the light into its different frequencies or wavelengths.

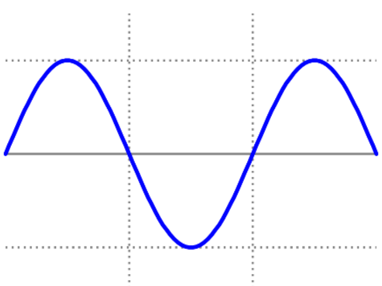
In much the same way, the covers over your office lights, frosted bulbs etc. act to diffuse the light, allowing it to spread more evenly around a room and reduce the harshness visually (#1).

This concept is the same for audio waveforms, except for the frequency range. Visible light operates in the range of 430 – 750 trillion hertz, audio from 20 – 20Khz.

When an audio wave hits a flat, or even curved, surface, the resultant reflection is specular in nature. That is to say that the wave is reflected in a single phase, much like the single color light we see from a prism. This is in keeping with Snell's law which only determines the angle of incidence, not the nature of the waveform. When an audio wave encounters a diffuse surface, it is broken up into many elements that are mixed in phase (think white light). In a well-designed diffuser, like a Schroeder QRD, the waveforms are returned into the atmosphere in groups of mixed-phase frequencies that lead to a more audibly coherent wave plane. This coherence is due to the different depths of cells in the design.

Imagine a sine wave where the reflection, such as a flat wall, is singular in phase (left image).

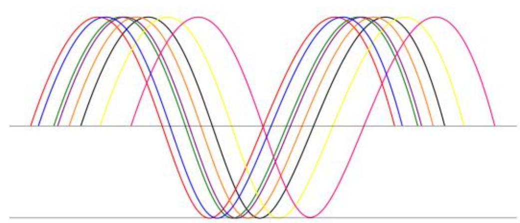
Specular Reflection



Now, imagine a sine wave broken up into multiple phase angles

(Right image)

Diffuse Reflection



This represents the components of a diffuse waveform.

Once we begin to understand the nature of diffusion, and what it takes to create a diffuse surface, we can begin to understand what it takes to test diffusers. We can also begin to understand why a singular chart is insufficient to comprehend the complex nature of these devices.

I would like to acknowledge the foundations laid by those who developed the tests being discussed here. This would include people like Vorlander, Mommertz, D'Antonio and Cox to name a few. The work they have done has led to the further developments you will read about in this article. Further advancements in technology since the development of both ISO tests have led us to establish better capabilities of seeing what diffusion for what it is as opposed to assuming certain facts not necessarily in evidence.

Scattering and Diffusion, what's the difference?

ISO 17497-1 is referred to as a "scattering" test. In truth, this means is that the test is random incidence i.e. it has no directional information. It is conducted using a reverb chamber, a rotating table with the diffusers mounted to it, and (6) or more microphones placed in various spots in the room. The room is tested both empty and with the test samples stationary and rotating, and an energy loss coefficient is derived from the comparison of the two tests.

Part of the problem with this test is that it takes place in a reverberation chamber. By definition, these chambers are diffuse fields. Testing diffusion in an already diffuse field is much like testing absorption in an anechoic chamber. While it could be done, it's difficult to separate the room from the device under test (DUT).

Reverb Chamber set up for ISO 17497-1 Scattering Test

ISO 17497-2 (AES 4-id) is referred to as a “diffusion” test. This term is somewhat disingenuous inasmuch as it assumes that the data that you see in the final output is complete data. However, the -2 test artificially removes specular reflections and purportedly leaves only diffuse reflections across the entire tested bandwidth. This, however, is not how energy loss occurs in actual use. Specular reflections are a component of a diffusers performance. Unlike the -1 test, the data is given as a polar response in 5° increments, typically in one plane.

It should be noted that ISO 17497-2 has often been mistakenly used to show the performance of geometric devices such as curved clouds, pyramids, barrels etc. As will be shown later in this paper, these devices are not diffusive, but are specular reflectors. Such data cannot be accepted as accurate or relevant given the nature of these devices.

To conclude, scattering as tested under ISO 17497-1 is the energy being reflected from the surface of the device under test (DUT) with the data presented as random or non-directional. ISO 17497-2 measures the diffuse energy only reflected from the DUT at 5° increments giving a partial polar response at one plane. Neither test, even combined, provides an accurate picture of the performance of a diffuser.

What we conveniently chose to forget

Aside from the obvious problem, not being able to show both specular and diffuse reflections in the same display, there is another serious issue with the real-world application of the ISO standards. We’re going to speak to the physics majors here, and ask you to recall your course(s) in which you learned about Dimensional Similarity.

Dimensional Similarity is primarily practiced in fluid mechanics, but its principles apply to any testing in which scale models are used as prototypes for full-size units. In its simplest form, the principle calls for any test data in which a scale model is used requires the scaling of all environmental conditions as well. In other words, if you want to test something in scale, you must scale the air as well.

This principle is well-known in aircraft design, for instance, where the test tunnel will be populated with a gas other than oxygen to match the scale of the DUT. There are numerous early examples of failed plane designs where this principle was not used.

Unfortunately, the majority of practitioners of diffuser testing use scale models for their testing in the ISO standards. The only caveat presented to adjust for the scale is almost always a simple 5:1, 4:1 etc. adjustment to whatever the scale is. This has been the case for many years and the resultant data is not reliable, in our opinion, in any way, shape or form. Diffusers are extremely complex devices and ignoring basic physics standards, like Dimensional Similarity, that have been around for over 100 years, does not make them go away.

Coefficients…anything but efficient

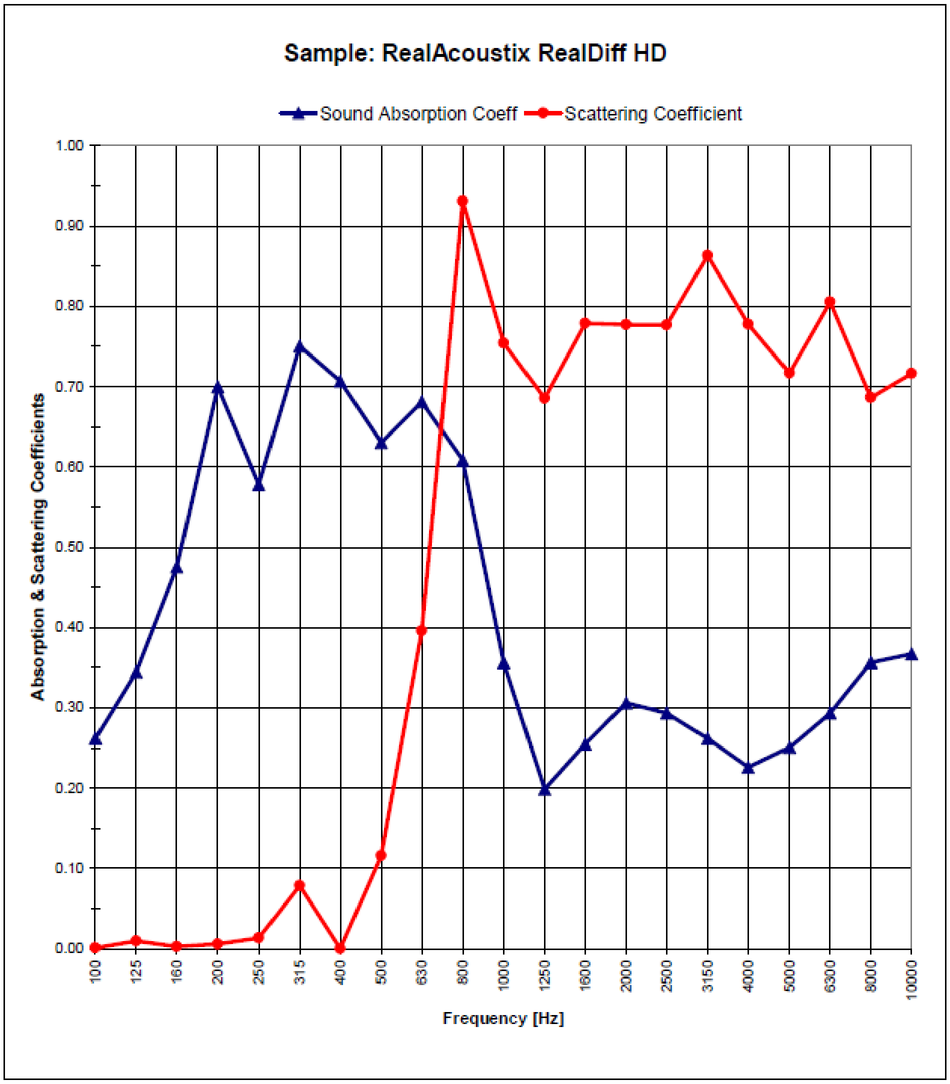
For more than 5 decades we in the acoustics community have been subjected to the thought that coefficients are the simplest and best method to present acoustic test data. The problems associated with tests, such as ASTM C423 or ISO 354, are well known by most acousticians. Lab variances have been reported as much as 45% in round-robin tests. The coefficient scale, which most assume means that 0 = 0% and 1 = 100% (not true, by the way), has been the cause of much grief and consternation over the years.

While steps are being taken by both ISO and ASTM to reduce the errors in the absorption test, the problems associated with the 17497-1 test are not receiving any attention. While still in use in academic circles, the public sector, including the authors, have determined that its accuracy is highly questionable and cannot be viewed as having any real validity at this point in time.

In the case of ISO 17497-1, a coefficient test, the accuracy of the test came into question when a design by one of the authors was brought into the lab. The unit is a highly modified version of QRD design. It should be noted that previous tests of more conventional QRD's, using this standard, yielded result that look like the following graph (next page):

NWAA Labs

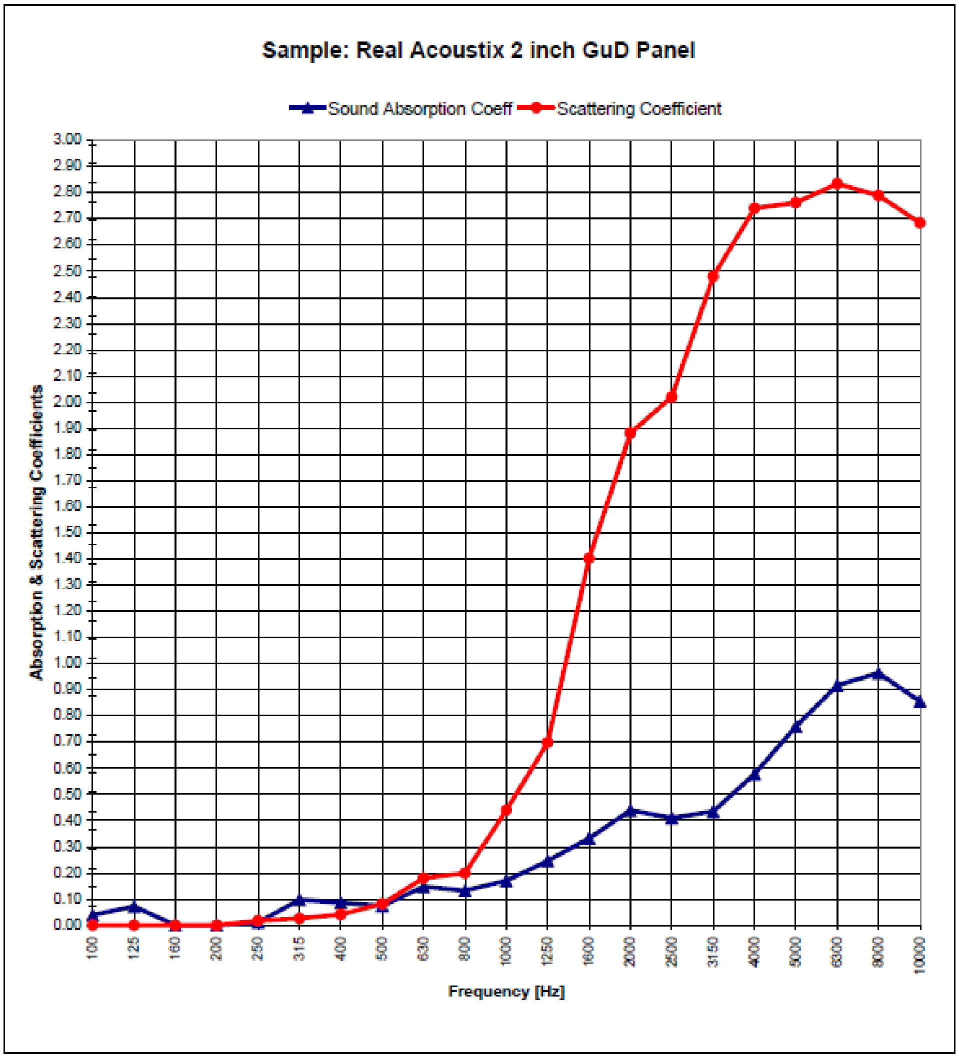
25132 Rye Canyon Loop
Santa Clarita, CA 91355
(253)-973-1018



The blue line represents absorption and the red line is supposed to be diffusion. These types of results could be deemed to be reasonable under most conditions as it lives within the expected confines assumed by most to be accurate. It might be so if there were some way to define the nature of the waveforms, which there is not.

However, when this new design was tested in the same lab and under the same conditions, here was the result:

NWAA Labs
90 Tower Blvd
Elma, WA 98451
(253)-973-1018



Note that the results, the coefficients, exceed 2.80 in the diffusive range. This test was conducted (7) times to ensure the results. This would indicate that the panel actually amplifies the signal, which is beyond believable, of course. While this is certainly a worst-case scenario, it is all-together too common and shows the Achilles heel of the -1 standard as well as coefficients in general.

The question that really needs to be asked of the acoustics community is why have we settled for coefficients when they are so susceptible to error? In addition, why would we want non-directional/random incidence information when directional information is so much more useful? Yet, there are those who are still looking for this information assuming that it is pertinent to their designs. In any reasonable thought process, this is truly a large step backwards in assessing the performance of an acoustic device.

What we have been looking for… and where it is

Now that we have covered the basics of the mess that has been created by both the manufacturing industry and, in some cases, academia and even laboratories, regarding the current diffusion test standards, where do we stand right now?

For the last 5 years we (the authors) have been working on a new diffusion standard that, we believe, has the power to answer most of the questions acousticians have regarding diffusers and diffusion testing. The best part about it is that it uses existing technology that is well-vetted and has been around for years.

The challenge to this test is that its data output is not just a simple graph. For the acoustician, designer or even the layman looking for a simple answer or one graph to define the character of diffusion and diffuser performance, it is going to require a paradigm shift in thought processes and study of the matter. Some will welcome the incredible depth of data available, and the answers it provides. Others will, out of habit or unwillingness to accept change, want to resort to the old standards that tell us almost nothing. The choice is, of course, yours.

The New Standard

In our work on the ASTM Acoustics Committee for the last 5 years, we have developed a test whose basic construct is based on the AES 56 directivity test. For those not familiar with AES 56, it is the standard by which speakers are tested for polar response described using magnitude and phase response. There is a wealth of data available within it that is not available in any other platform.

The most exciting part of this is the potential to use this data in room acoustic design programs such as EASE. If thought about properly, a diffuser using this data can be viewed just as one would view a speaker. The only difference is that we are testing using first order reflections instead of an originating signal. In other words, it is a speaker without a voice coil.

On the following pages we will show you some of the data output that this proposed ASTM standard can provide. If, after reviewing this information, you are not convinced that it provides more information than you have ever seen before, you might want to re-read the last 2 lines of the previous section, "**What we have been looking for… and where it is"**.

The test consists only of full-size samples as to avoid any issues with Dimensional Similarity. It also tests each unit in a full 360° pattern, at 5° increments, as to ensure the most complete data set available. Information is available to whatever degree one desires to review it by simply downloading a free reader application.

Lastly, the ability to finally see diffusion in a phase display is available. This ability alone separates this new standard from anything else in the world. We hope that you will take a few minutes to look at the data available with this standard.

The Proposed ASTM Diffusion Standard

The criteria set out for the new ASTM New Diffusion Standard (ANDS) were designed by the authors and the ASTM Acoustics committee to avoid the problems addressed in this paper with the existing standards. They are as follows:

1. Free-field or anechoic test field
2. Full-size specimens only
3. Inclusion of both diffuse and specular reflections
4. Displays of magnitude, phase, polar mapping and having frequency selection as minimum output data
5. Non-coefficient based
6. Adjustable to specimen size
7. Measurements (typically) in the far-field

The final version of ANDS meets all of the above criteria and more. It avoids the complications associated with previous standards. Several manufacturers, including this author, have already adopted this test despite it not yet being approved as a standard. Why, you might ask? Because for the first time in the history of acoustics, we can actually see what a diffuser is doing to a degree heretofore not realized.

It should be noted that the sample size directly affects the low frequency data of the test. The sample width and length are equivalent to the lowest frequency able to be tested. This is generally not a problem as very few diffusers have relevant performance below 250Hz.

ANDS is conducted in a large free-field space where there are no secondary reflections that could skew the data. This is important inasmuch as the data capture of the first reflection from the excitation signal must be unencumbered by secondary reflections. A photo of the test rig looks like this:

Diffuser under test (19) microphone array Excitation source (speaker)

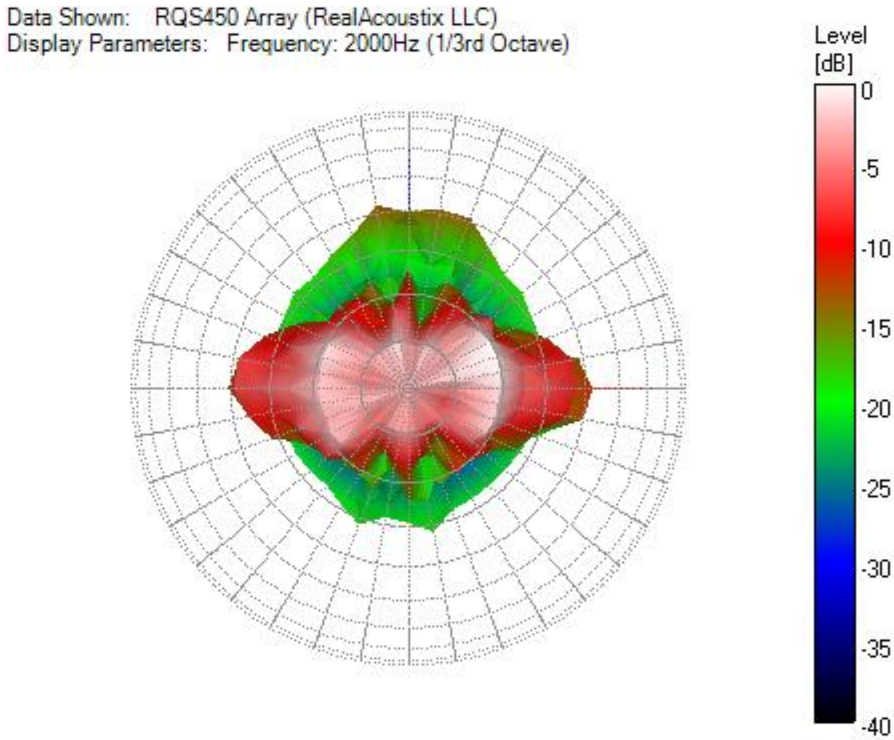
The DUT automatically rotates in 5° increments at which point a short swept sine signal is applied (approx. 140ms). The resulting 1st reflection is windowed out for each of the (19) microphones and the data is stored for computation later on. The result is 1368 samples that then undergo a Fourier transform and are combined to provide the directivity balloon data.

A sample device, a standard Schroeder one-dimensional QRD, is shown in the following test data output. In it, you will see the some of the behaviors that one would expect from such a design. Other behaviors, such as diffuse frequency response, will be challenging because, for the first time, we can see the actual diffusive nature of the device. To some familiar with diffuser designs, this will come as quite a surprise.

It is hoped that this data will open up new conversations as to not only what constitutes a "diffuser", but also as to how we can better use these devices to accomplish room designs. It takes much of the mystery out of the art and replaces it with the science that it is, and should be.

Now, let's look at the data output:

Balloon Display

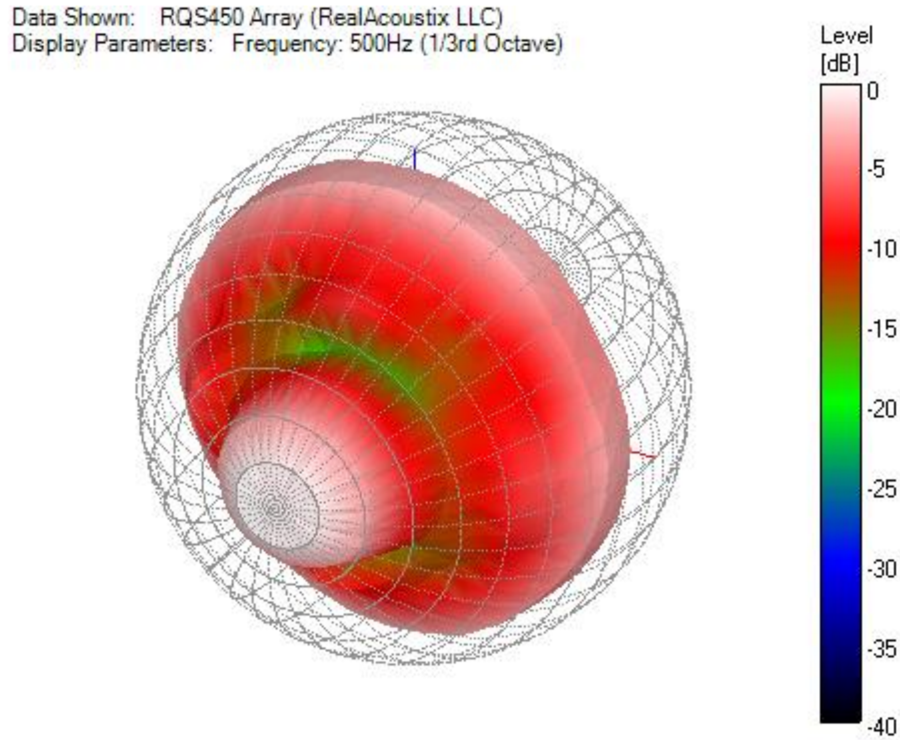


In the Balloon Display view you may select any frequency data set from 25Hz to 20KHz. Some of the lower frequency information will be limited dependent on the size of the specimen. Some of the high frequency information will be less useful due to air absorption. This, however, can be compensated for in the viewer settings. The actual useable frequency response is more along the lines of 250Hz to 10KHz.

You will notice that the dB scale on the right indicates the attenuation of the reflection. Because this is a one-dimensional QRD, you see that the bulk of the reflections are in the horizontal plane, just as Schroeder defined them. Very little energy exists in the vertical plane.

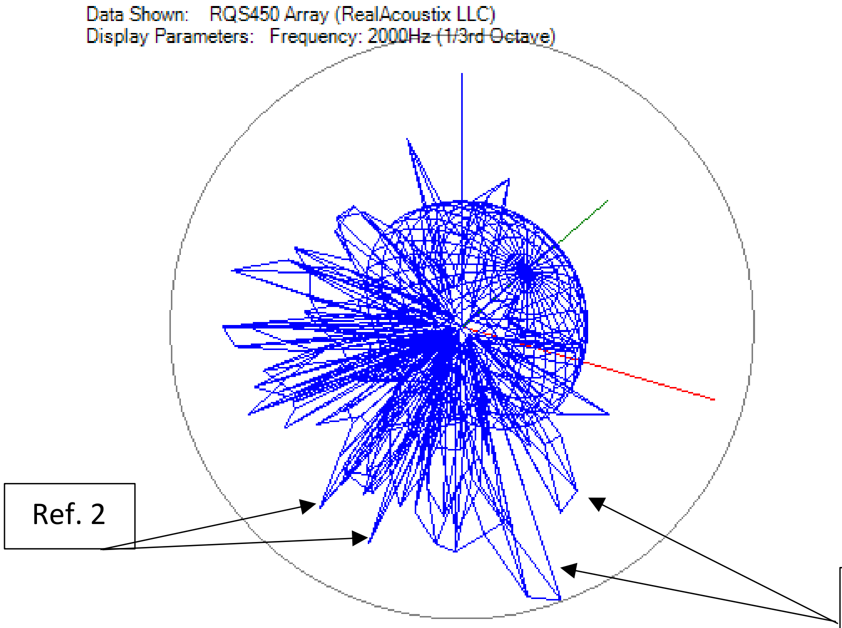
Please note that the Schroeder design frequency of this device is 450Hz. Historically, the reflections above the design cutoff frequency were assumed to be diffuse in nature. This example is the polar plot at 2000Hz as seen above the plot.

Now, let’s see what the plot looks like at a point just above the LF design frequency:



This is the same DUT at 500Hz. As you can see, it seems to have a great deal of reflected energy, but what is the character of that energy? It's difficult to tell from just an attenuation plot. It is evident from the plot that, unlike the previous 2KHz. plot, there is little deviation in the reflection. In fact, the smooth, round nature of the plot would indicate that the DUT has very little effect on the wave. The wave is simply reflecting off of the overall surface with a small spike of energy in the center. This is more indicative of a specular reflection. The energy displayed in the surrounding "donut" is energy being reflected from the vertical surfaces of the perimeter of the DUT.

This is where we must look at other data to determine exactly what this unit is doing.

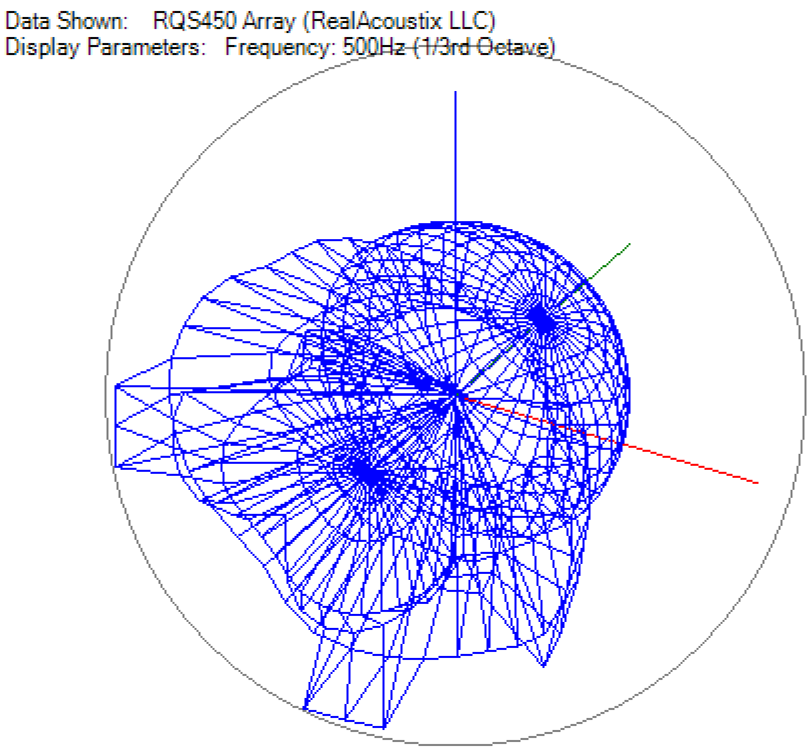


The picture to the left is a phase balloon. It may look confusing at first, but a further look into its detail tells us a lot about the diffusive performance of the DUT.

The large bands on the extreme sides of the plot (ref. 1) are more specular in nature. The sharper spikes seen closer to the center (ref.2) represent diffuse, or mixed phase, reflections.

This reference is at 2000Hz, well within the operating range of the DUT.

Now, let's look at the DUT at just above the LF cutoff frequency:



At first glance, this window can confuse those not familiar with phase balloons. Remembering that this is a 1D QRD with a design frequency (LF) of 450Hz, it is natural to assume that we will see mixed phase reflections coming from the DUT.

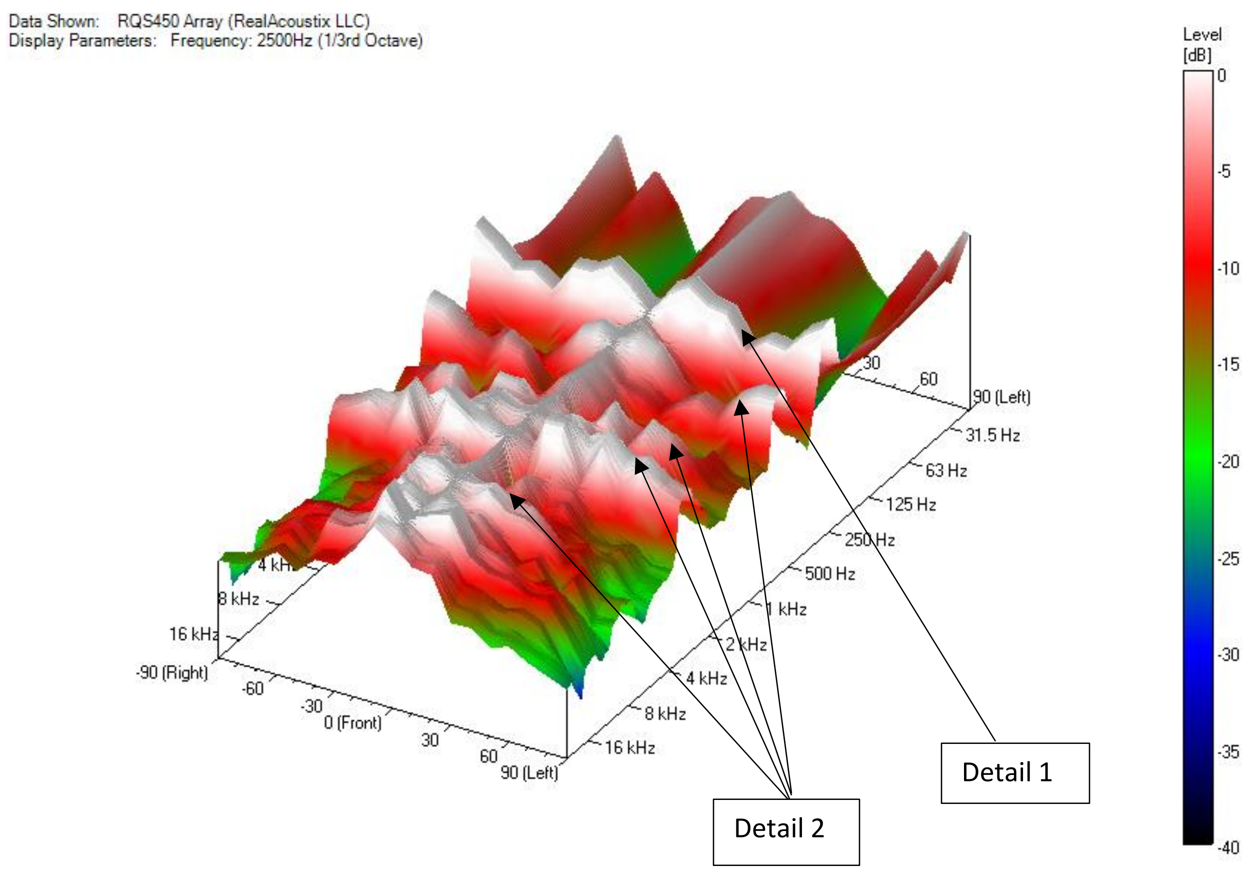
This is where the information provided by ANDS gives us great insight to the actual performance of the diffuser.

What we see in this window, 50Hz above the cutoff frequency, are simply coherent i.e. specular reflections. The large "petals" (resembling flower petals) are coherent reflections at the chosen frequency. There is little or no diffuse information in this window.

It has been discovered, through implementation of the ANDS test, that Schroeder diffusers, 1D or 2D, do not really become diffuse until at least 2 octaves above the design cutoff frequency. As can be seen in the graph above, the QRD is simply acting as a specular reflector at 500Hz.

Horizontal and Vertical Mapping

Another one of the many graphic tools available in ANDS is the ability to look at the overall character of the diffuser over the entire frequency band. This can give us what we consider to be the best overall view of the diffusers performance. These maps give us a full view of the frequency range of the diffuser, the frequencies at which it is most efficient and the polar response, and associated attenuation of those balloons, all in one view. Let's take a look at this same QRD in a horizontal map:



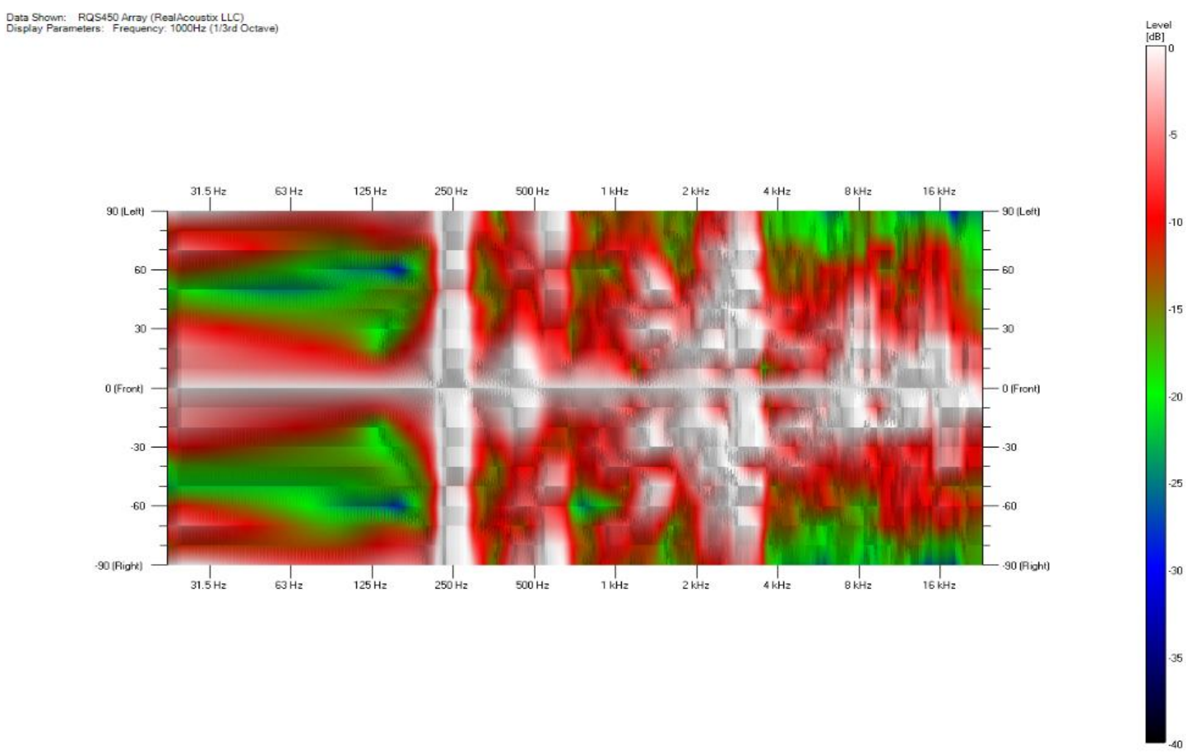
Horizontal Map/3D view

This Horizontal Map of the QRD tells us many things about the performance of the DUT. In Detail 1 we see the first signs of the effects of the reflections from the DUT. At 250Hz, although specular in nature, the DUT is breaking up and spreading the reflections out over the span of the unit.

In subsequent zones (Detail 2) we see the effects of the design parameters of the prime number chosen in the design of this unit (prime 11). The high efficiency of these zones is directly related to the chosen cell depths of the DUT. QRD's have groups of cells, based on their prime number, that are essentially "tuned" to that band, or group, of frequencies. This is why we see hills and valleys in the performance curve of the QRD. For many years it has been assumed that higher prime numbers lead to better performance in QRD's. This is evidence that there is truth in that conclusion.

A final note about the Horizontal Map is that one will see that above 6KHz the polar response narrows significantly. This may be a direct reflection of the speaker used as the impulse response for the test. Most speakers also narrow with increased frequency. Further study is required to assess this behavior. Needless to say, all diffusers will, to one degree or another, be a reflection of the impulse signal that they encounter.

Horizontal Map in Z view

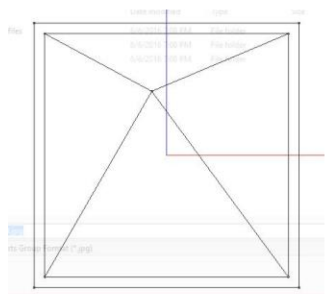


What's Not a Diffuser?

One of the most interesting results in developing the ANDS test is the ability to now truly differentiate between what constitutes diffusion and a diffuser. Unfortunately, the manufacturing and marketing segments of the acoustic industry have muddied the waters for decades leaving us calling many devices diffusers that really have no diffuse nature at all.

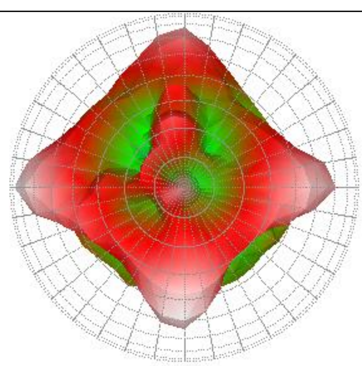
This is not to say that acoustic treatments such as pyramids, barrels, curved and angular surfaces have no place in acoustic designs, of course they do. They serve to re-direct energy in multiple directions. However, there is no mistaking them for diffusers.

Let's take a look at a standard pyramid as an example.

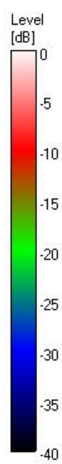


In the graphs below you will see that the performance of this standard golden pyramid design is specular in nature, as evidenced by the four distinct lobes on each side. The angles and bands are clearly visible in the graphs as specular reflections.

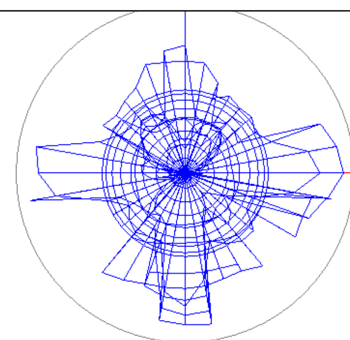
2KHz



Polar Balloon



2KHz



Phase Balloon

The authors have chosen to refer to devices based on simple geometric shapes as "re-directors" and not diffusers. While it would be difficult to get the acoustic industry to adopt new definitions for these devices, the reality of their actual performance criteria dictates that we look at them differently than devices that actually produce diffuse reflections.

A World of Views

To include all of the various graphs available to quantify a diffusers performance under the ANDS test would require more room than this paper can, or should, provide. However, as the reader can hopefully see, the information provided by ANDS is far greater than anything heretofore available.

Another distinct advantage of the ANDS test is the ability to use this information in room design. Because the base information is the same as is used in the speaker data in programs like EASE, for instance, this information can be used to place a diffuser or re-director in any location and view it the same as one would a speaker. This can be accomplished by using the GLL data just like a speaker that is mounted in/or on a wall. If the data used describes a 2ft. by 2 ft. sample, the designer places them in an array that you would design, calculate them together as a cluster and then use the resultant cluster balloon to represent the entire wall/array. This will reduce the computer effort to the equivalent of a single speaker.

Be aware that the specular reflections that remain, even after you have placed the array will still be up to 10-15db higher magnitude than any diffuse energy that is induced to the reverberant field. Later versions of EASE and other programs will use this data as intended by setting the output energy to not be induced until a ray in detected from the acoustic source used in the room. In the meantime, it is possible to see what kind of energy is being reflected off of a treated wall by substituting the diffusers for the acoustic sources in the model. This is a workaround that can be used until the new versions are available.

Further white papers on this subject will be forthcoming, detailing the methods to be used with figures and illustrations included.

Conclusion

Because this test is now being used by several manufacturers and is in the analysis and approval stages in ASTM, it is hoped that the acoustics community will begin to accept and adopt this information as a substitute for the less reliable ISO standards. The authors have taken every effort to present this information as accurately as possible.

For more information about this test, including downloading the free GLL Viewer, please contact either of the authors or any manufacturer who presents this test data for your consideration. We thank the many members of the ASTM Diffusion Committee who have contributed to development of the ANDS test and acknowledge the contributions of the Audio Engineering Society in allowing the use of AES 56 as the basis for the new proposed ASTM standard.

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