Measuring Curved and Corrugated Diffusors Using Traditional Methods

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ABSTRACT

The construction and evaluation of diffusion devices are at present often based on unsupported assumptions as to the relative performance of disparate design styles and often employs unnecessarily complicated measurement techniques. Well known, and reliable methods exist for measuring and comparing the gross acoustic properties of loudspeakers and by applying these methods to the evaluation of diffusion devices similar measurements of performance can be made with relative ease. The results obtained can allow valid direct comparison, all without undue complexity, or any risk of incoherence. The design of diffusors has evolved from implementations using curved surfaces into a predominance of alternative implementations using corrugated surfaces with the optimal dimension for the crenulations often divined from various interpretations of number theory. Traditional loudspeaker directivity and frequency response magnitude measurements demonstrate that traditional curved surface diffusors are markedly superior to corrugated shape diffusor designs. Such measurements can be reproduced for custom designs with relative ease and such practice would be beneficial to acoustic space designers and contractors in need of diffusion devices constructed to meet specific needs.

1 - BRIEF HISTORY

An acoustic diffusor is a device that scatters incident sound energy toward a larger scope of angles of reflection than a flat plate or typical smooth room boundary surface. Diffusors are used to alter the reverberant characteristics of a room to yield a better approximation of a diffuse sound field and are considered an important tool for manipulating the acoustic field in environments adapted for both listening and for taking acoustic measurements. Diffusors are standard fixtures used in reverb room test chambers, control rooms, mixing suites, sound stages, and musical performance venues and theaters.

Diffusion was in early instances accomplished by introducing irregularly shaped protrusions and indentations to room boundaries through architectural elements such as curved walls and ceilings, coffered ceilings, faux columns and similar decorative frieze work, or even adding elements to wall sections using “found” objects such as plumbing pipes. This early work was accomplish in a more or less random fashion and once installed was generally difficult and expensive to alter. Diffusion through architectural amendment evolved into the design of discreet optimized devices for accomplishing diffusion including a style of device that has come to be known as the “polycylindrical” or “poly”. Polys are simply curved panels or plates, and have been made in various ways including building a fixed radius rib structure which is then sheathed to create a more or less regular hemi-cylinder, or by buckling panels through the application of compressive force along two opposite edges to create sweeping curves with bends of a variable radius across the face of the device.

In 1978 Manfred R. Schroeder, a mathematician and acoustician, developed equations which created a scientific method based on number theory for creating corrugated surfaces with predictable sound scattering properties [1]. Schroeder’s work resulted in diffusion devices called acoustic diffraction gratings.

In recent years, many devices have been successfully marketed to practitioners in acoustic fields as standard parts for accomplishing diffusion. Expanding on Schroeder’s work, the design of diffusion devices has, increasingly over time, focused on units which present a corrugated surface to the room. The use of corrugated diffusers has been memorialized in important works well known in the acoustic field such as Leo L. Beranek’s, “Concert and Opera Halls: How They Sound”. This text and others contain descriptions of halls with diffraction grating type corrugated diffusors being successfully implemented. Other important and popular works such as F. Alton Everest’s “Master Handbook of Acoustics” and Don and Carolyn Davis’ “Sound System Engineering”, contain detailed descriptions of corrugated diffraction grating diffusion devices and numerous pictures of acoustically optimized spaces which incorporate such devices.

Despite the success enjoyed by corrugated surface type diffusion devices in the marketplace and their popularity in standard texts, there are few sources of published measurements of such devices which enlighten one as to their performance across both a full and continuous frequency range and from a full range of angles of incidence and observation. Measurements of diffusivity at only specific frequency bands and for a limited number of angles of incidence is particularly undesirable in the case of corrugated style units due to the fact that it is a well understood characteristic of diffraction grating type diffusors that they will exhibit alternating bands of efficacy and inefficacy across the band (frequently referred to as: "lobing") a defect which only worsens when units are used in groups mounted along side one another to cover significant wall or ceiling sections [2]. Also, many studies of diffusive measurement work toward a goal of a single number representation of an index of diffusivity forgoing the desirable result of instead presenting a measurement of reflections off the device under test across a wide band of frequencies and across a wide range of angles of incidence and observation.

2 - INTRODUCTION

Using a single number index to analyze diffusor performance is no more desirable than such a method would be for the consideration of a loudspeaker. Likewise, measurement of a diffusor which does not collect and present data across a broad frequency range with high granularity [smoothed to a large number of bands per octave] is not desirable – just as it would not be best practice in the analysis of a loudspeaker.

This study investigates the adaptation of simple and pragmatic loudspeaker measurement techniques to the purpose of making performance observations of diffusion devices by combining a wide range of frequency information together with a broad range of sampled angles of incidence and observation, and thereby seeks to illustrate variances in diffusive performance in a concise form using pragmatic techniques. Defining simple and accurate methods for the measurement of the performance of diffusors using common tools of the trade will provide practitioners in the acoustic arts with the means to test and develop custom diffusion devices just as they might test and develop custom speaker systems and it is the purpose of this study to encourage such efforts by demonstrating practicality. Specific reference is made to the work of Gander [6] in which he detailed the use of an adjustable time window to produce simulated free field measurements of loudspeakers in a ground plane environment. Gander's work is foundational to this study.

The devices measured in this study include a curved surface polycylindrical diffusor and two representative samples of diffusion devices based on corrugated surface design principles. Collectively these devices represent a sample of the styles of diffusion units practitioners in the acoustic field might custom build for a project, or might select for purchase in order to accomplish diffusive treatment.

3 - THE DEVICES UNDER TEST

The devices tested (Device Under Test: "DUT") were: a curved surface polycylindrical type diffusor titled "*Euler-Bernoulli Diffusion Plate"* from Ready Acoustics, LLC, a phase reflection grating diffusor of pattern 1, 4, 2, 2, 4, 1 [Figure 4], and a spaced hemi-cylinder corrugation type diffusor titled "*D1 Diffusor"* manufactured by GIK Acoustics [Figure 5].

3.1 - EULER-BERNOULLI DIFFUSION PLATE

The Euler-Bernoulli Diffusion Plate ("E-B Plate") is a prototype diffusor made by Ready Acoustics, LLC based on the traditional polycylindrical design in the form of a buckled plate and presents a smooth curve across its front surface from side to side with a radius that varies from edge to edge. The unit is bilaterally symmetric along its long axis, has dimensions of 24x48x8" [60x120x20 cm], and is made of a thick heavy plastic plate with slots in the sides so it can be inserted in a "Chameleon Acoustic Frame" of the same manufacturer. This unit was tested mounted to a 4" [10 cm] "Chameleon Bass Trap" as suggested by the manufacturer. The fancy name is derived from the works of mathematicians Euler and Bernoulli on equations which describe the deflection of beams under compressive stress and which also purportedly describe the shape of the device.

3.2 – QUADRATIC PHASE REFLECTION GRATING

A typical phase reflection grating diffusor derived from an interpretation of Schroeder work cited above is comprised of a series of shallow wells aligned in parallel with well depths defined by a pseudorandom sequence such as a quadratic residue. An early version of this style of design has been immortalized in what is perhaps the most famous of all diffusion units, the *QRD 734®* manufactured by RPG Diffusor Systems, Inc. This firm produces many innovative diffusion devices including optimized curved surface devices. Because of its age and simplicity the 734 unit appears frequently in the texts cited above describing and depicting the implementation of diffusion devices. This unit has served as the inspiration for myriad diffusors built by others of more or less equivalent dimension and shape. The "QPRG" device tested appears to be a faithful copy of the original *QRD 734* as the unit is bilaterally symmetric along the axis parallel with the wells, which are of equal width and which follow the sequence 1, 4, 2, 2, 4, 1 as to relative depth, is a fairly hefty and rigid device made from MDF with a hardwood veneer, and has dimensions of 24x48x8" [60x120x20 cm].

3.3 – GIK - D1 Diffusor

Many corrugated diffusors do not follow Schroeder's work but instead incorporate a pattern of crenulations which have no known basis in number theory of which the authors are aware [3]. The "D1" is a diffusor manufactured by GIK Acoustics and is an example of seemingly random approach to crenulation pattern. Rather than a row of wells across its front surface the D1 creates corrugations by way of a series of parallel hemi-cylindrical protrusions of varying radius and width spaced across its face with occasional gaps. The unit is thin-walled lightweight moulded plastic device and does not exhibit bilateral symmetry along the axis parallel to its corrugations. The D1 has dimensions of 24x24x6" [60x60x15 cm] thus for testing purposes two GIK D1 units were stacked one atop the other in order to accomplish a unit of similar total dimension to the two other DUT.

4 - METHOD

This study proceeded by measuring the time and frequency domain characteristics of the reflections from each diffusor DUT in circumstances of various angles of incidence for the sound source and various angle of reflection for the observation positions. These measurements were made by exposing the DUT to a broadband test tone emitted by a loudspeaker and then recording the reflection using a measurement microphone. A radial array of microphone and speaker positions were sampled in turn and using adjustable time window impulse response techniques the results were processed by personal computer to demonstrate the varying performance across both a wide range of frequencies and a wide range of angles of observation.

These measurements were performed in a room with the DUT located remote from all walls a distance greater than the distance from the DUT to the measurement microphone adapting the ground plane measurement method described by Gander [3]. Ground plane measurement calls for the loudspeaker under test and the microphone to be placed on the same flat surface. In our adaptation of this method we placed the DUT, the sound source loudspeaker and the microphone on the same flat surface. As all devices are on the same planar surface the measurements are not perturbed by floor reflections. Figure 1 depicts an example of this arrangement.

Figure 1. Ground Plane Measurement Method setup with speaker, microphone, and Device Under Test (DUT)

There are many measurement systems and tools capable of performing these operations; for this study the MLSSA Acoustical Measurement System together with an IPSIS 13 monitor speaker and a Bruel & Kjaer 4007 omni directional microphone was used for data collection, while ARTA Audio Measurement and Analysis Software was used for post processing.

The floor area in front of the DUT position was marked with two arcs, one with a 2 meter radius and one with a 4 meter radius and then radial lines at 15 degree increments were drawn from the middle of the back edge of the DUT. With such register marks in place a series of practical sound source and observation positions were marked and available for repeatable measurement. As shown in Figure 2, the intersection of the inner 2 meter arc and radial degree lines denote proposed microphone positions, while the outer 4 meter arc and radial line intersections denote proposed loudspeaker positions.

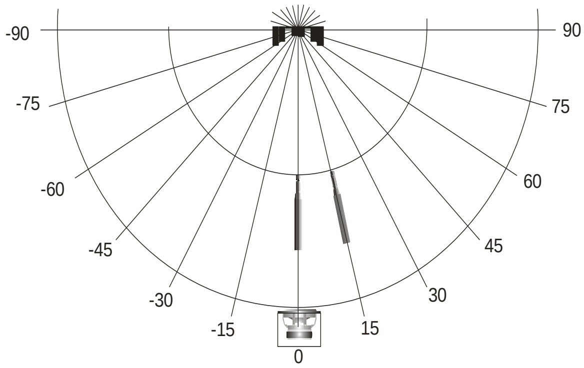


Figure 2. floor layout grid for positioning the DUT, the loudspeaker and the microphone in a radial array

Under these conditions sample measurements from a wide range of positions for both the loudspeaker and the microphone were taken and it was confirmed that background noise was not a limiting condition. It was further determined that:

i) Varying the speaker or microphone placement in increments less than 15 degrees produced insignificant refinement of the measurement;

ii) At the extreme positions for angle of incidence the diffusivity of all devices tested collapsed to nil. We hypothesize that at such angles the diffusive properties of the face of the DUT are diminished to levels impossible to differentiate from the scattering (diffraction/edge effect) occasioned by the test signal impinging on the sides and corners of the DUT. This was confirmed by replacing the DUT with a flat sided wooden box of similar dimension to the DUT and obtaining similar results in reflected signal versus those obtained by each of the DUT at the same extreme angles.

Having explored the above described bounding properties of the test rig and of DUT performance, the following process was determined for measuring and reporting the diffusion properties of the three DUT. Each of the three diffusors was in turn subjected to a correlated test sound signal at normal incidence [zero degrees as shown in Figure 2] and discreet measurements were taken at eleven of microphone positions ranging from +60 to -60 degrees. The reflected sound for each observation position was recorded and then the speaker moved along the 4m arc to a different source location ranging from zero to +60 degrees whereupon the measurements were then repeated for each of the eleven observation positions.

When taking measurements by this method the loudspeaker emits a signal sound which then reflects off the DUT and is recorded by the microphone. In addition to the reflections of the test sound from the DUT, the microphone also records the reflections arising from the ceiling and walls of the room, therefore post measurement one must separate the desired measurement of reflections arising from the DUT from the reflected sound coming from the room boundaries. This is accomplished by a process called windowing. A time window or block of data is selected from the measurement recordings for processing from each DUT data set separated by the time of its arrival at the microphone. The timing of the measurement window is adjusted via software so that it does not open until just before the arrival of reflections from the DUT at the microphone, and also so that the window closes before the arrival of reflections from the room's boundaries. The restrictions imposed by the time window allow the resulting measurements to focus solely on the reflections arising from the DUT.

It should be noted that by using a multi-track recording system and multiple microphones, all of the discreet observation position measurements for a given sound source angle of incidence [speaker location] could be obtained from a single test sound impulse, however the authors were determined to explore the use of a simple and inexpensive test rig in order to demonstrate that accurate diffusion measurements need not require large arrays of expensive equipment or complicated and specialized test facilities.

4.1 PRESENTATION OF MEASUREMENTS

A frequency range of 400Hz to 10kHz was established as being of interest and available for accurate measurement given the dimensions of the test rig and the room where the measurements were taken and thus a minimum window size of 3.5ms was used to post process the measurement data [low frequency accuracy of measurement is limited by window length – longer time windows allow measurement at lower frequencies, but such requires a greater distance from room boundaries].

The post processed data for every discreet speaker position and its related microphone positions are presented below as directivity sonograms and frequency response magnitude graphs for comparing each of the 3 DUT at each loudspeaker position.

The sonogram data are normalized relative to the zero degree position in order to allow visual assessment of efficacy across the frequency band [X axis] without interference from loudspeaker high frequency roll-off anomalies. Amplitude of reflection from the DUT is graphed over a range of 0 to -20 dB [color coded from red to blue], and over the range of angles of observation -60 to +60 degrees [Y axis with zero degrees incidence being the horizontal center line]. The frequency response magnitude charts have been smoothed to 1/24th octave in order to provide high granularity.

Results are shown below in pairs of graphs for each device at five different angles of incidence for the sound source [0, 15, 30, 45 & 60 degrees].

The first graph is a multi-color sonogram which illustrates across the vertical axis the amount of sound energy reflected from each device across a range of -60 to +60 degrees with the middle of the graph being 0 degrees. The horizontal axis of the sonogram shows how the device varies in performance across a frequency band from 400 to 10k Hz.

A device which reflected sound evenly to each side across the full 120 degree measurement range, at any given frequency, would produce a sonogram showing a single color from top to bottom at that frequency range, and if the device performed equally well all the way across the measured frequency band the sonogram would be a single color from left to right.

The second graph shows the frequency magnitude response measured of the sound reflected of each diffusor at five different angles of observation [0, 15, 30, 45 & 60 degrees]. Each coloured line on the graph represents a different angle of observation and the vertical axis varies with the strength of the reflected sound. If the source signal were perfectly flat [equal amplitude across the frequency band], a perfect diffusor would then produce a flat horizontal line for each line and all of the lines would be closely grouped.

5 CONCLUSIONS

A method is offered describing a simple but effective way to measure diffusion devices using tools common to practitioners in acoustic work and well understood techniques used for the analysis of loudspeaker systems. This method was applied to measure three diffusion devices, one representative of traditional curved surface "polycylindrical" shape and two others with a corrugated surface.

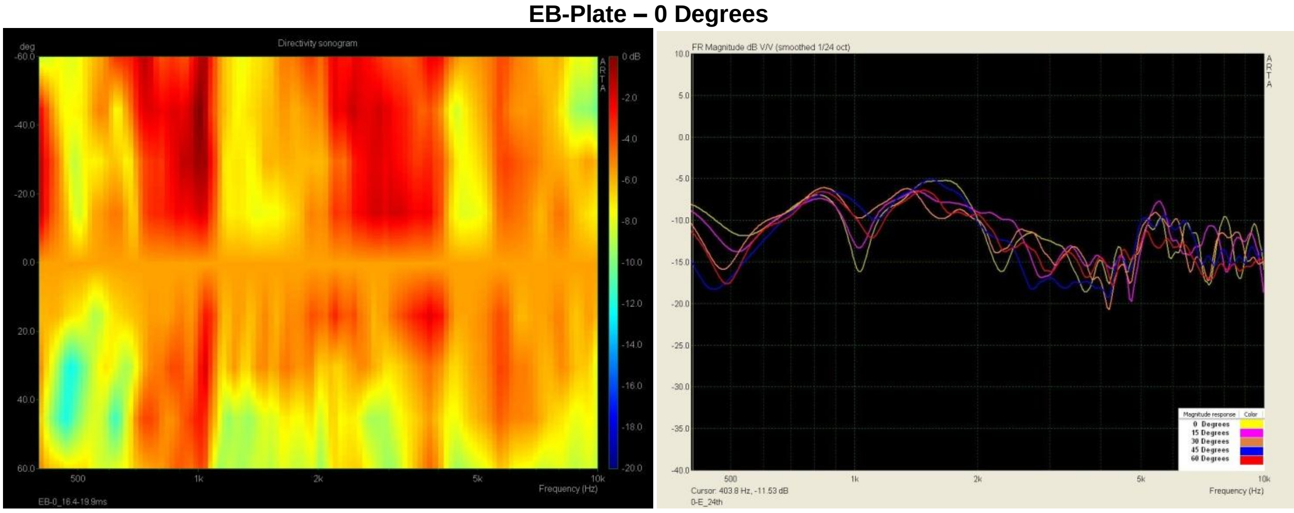
These measurements demonstrate that corrugated diffusors exhibit erratic behaviour per frequency and are only modestly effective at accomplishing the re-direction of impinging sound waves across widely varied angles of reflection. The curved surface of the polycylindrical device in comparison presents markedly superior smoothness of reflection response across the frequency band and more consistent angular dispersion of reflected sound regardless of the angle of incidence or observation.

Similar measurements can be taken for any proposed diffuser design using common tools of the trade, to wit: a personal computer of modest performance, a measurement microphone, inexpensive acoustic measurement software, and a modestly sized space with a flat floor. Practitioners in the acoustic arts are encouraged to further this work by sharing similar measurements with the public.

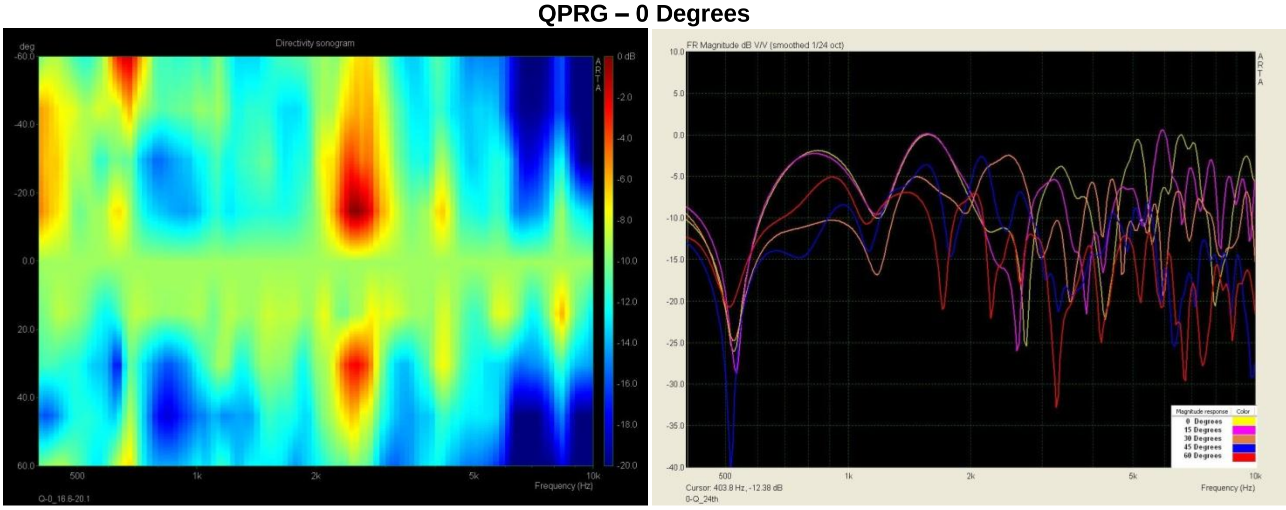
1. Schroeder, M. R.: "Diffuse sound reflection by maximum-length sequences". J. Acoust. Soc. Am. 57 (1975), H. 1, S. 149-150.
2. A. S. Angus and C. I. McManmon: "Orthogonal Sequence Modulated Phase Reflection Gratings for Wideband Diffusion", Audio Engineering Society 100th Convention, 11-14 May 1996, Copenhagen, Denmark, preprint #4249
3. M. R. Gander, J. Audio Eng. Soc. (Engineering Reports), vol. 30, pp. 723-731 (1982 Oct.).

5.1 SPEAKER AT 0 DEGREE POSITION

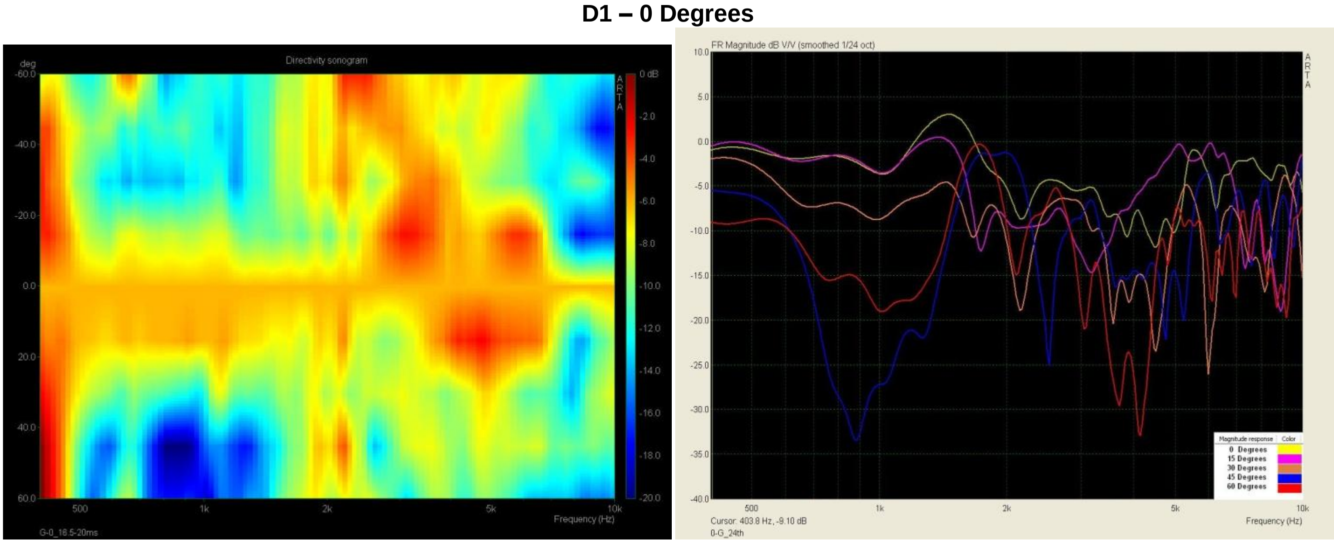
EB-Plate – 0 Degrees



QPRG – 0 Degrees

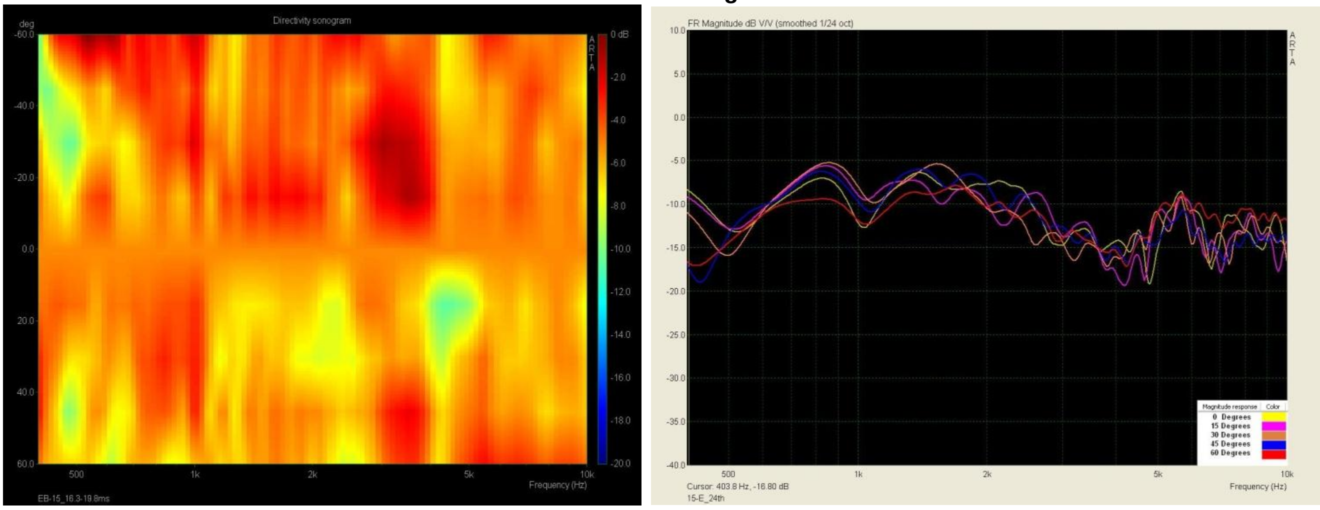


D1 – 0 Degrees

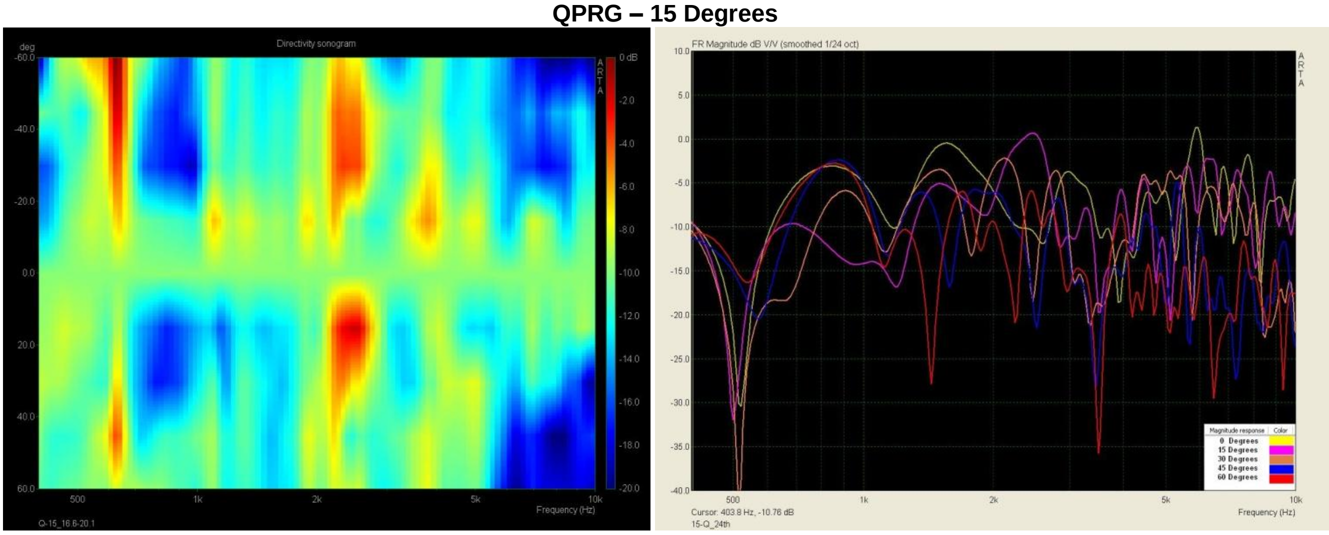


5.2 SPEAKER AT 15 DEGREE POSITION

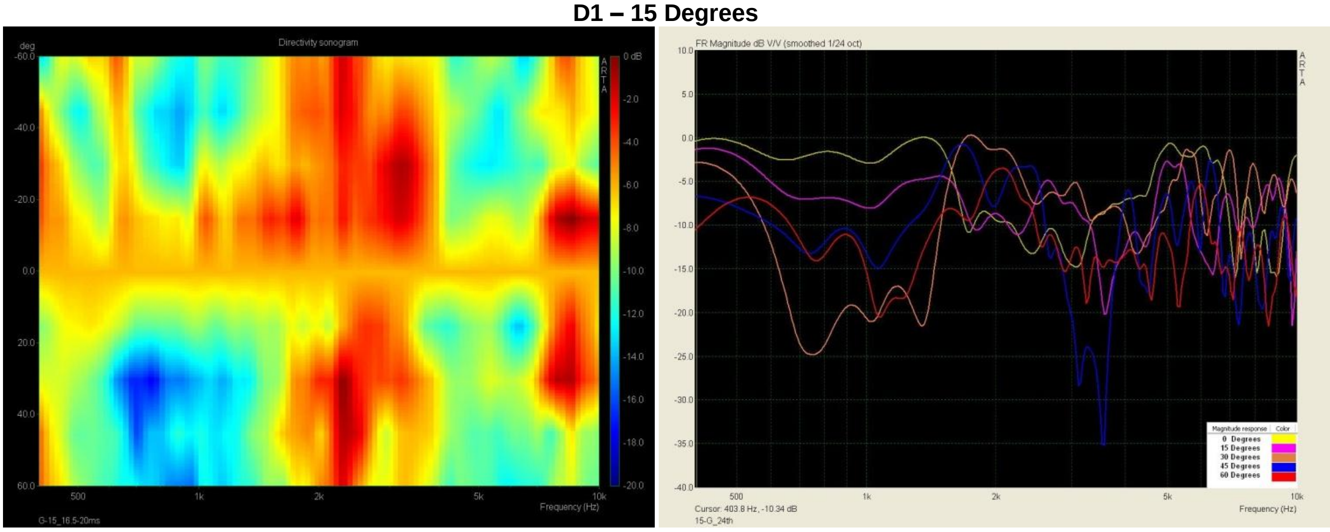
EB-Plate – 15 Degrees



QPRG – 15 Degrees

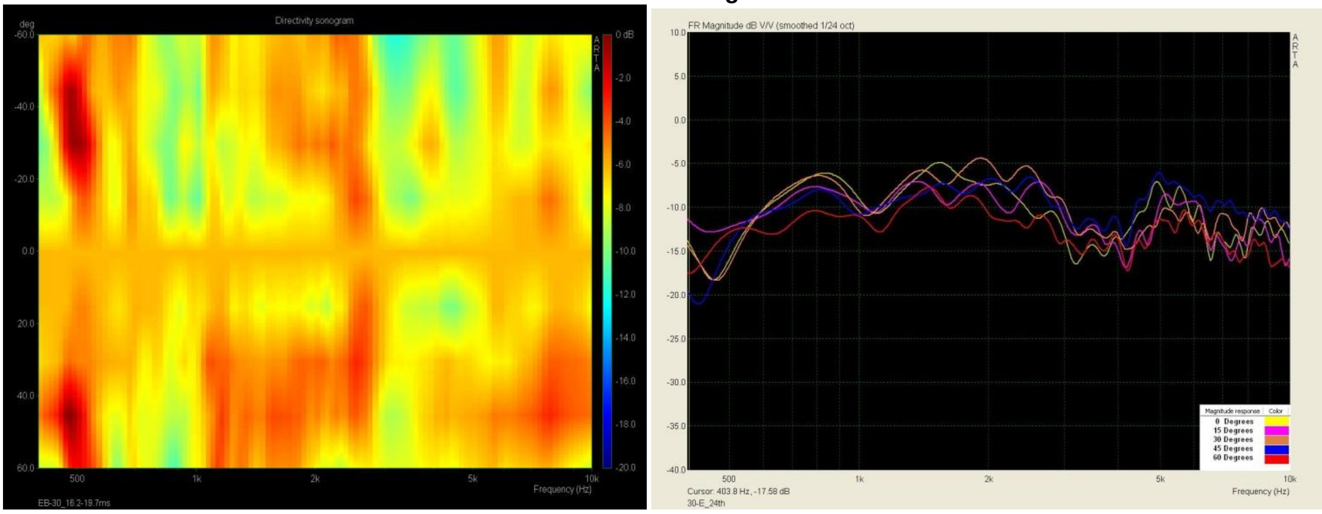


D1 – 15 Degrees

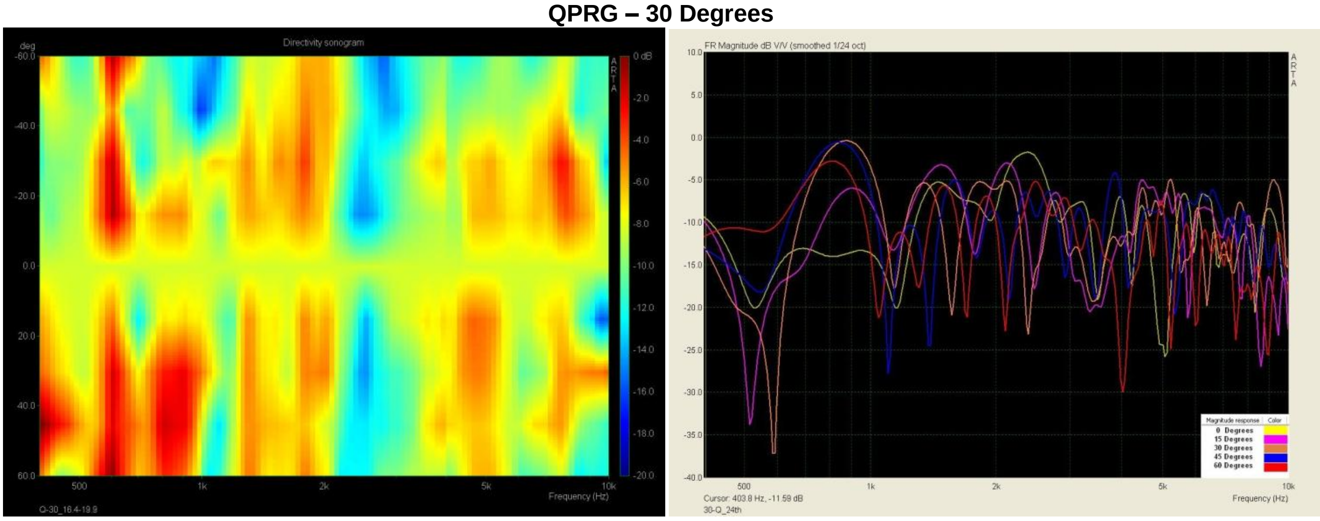


5.3 SPEAKER AT 30 DEGREE POSITION

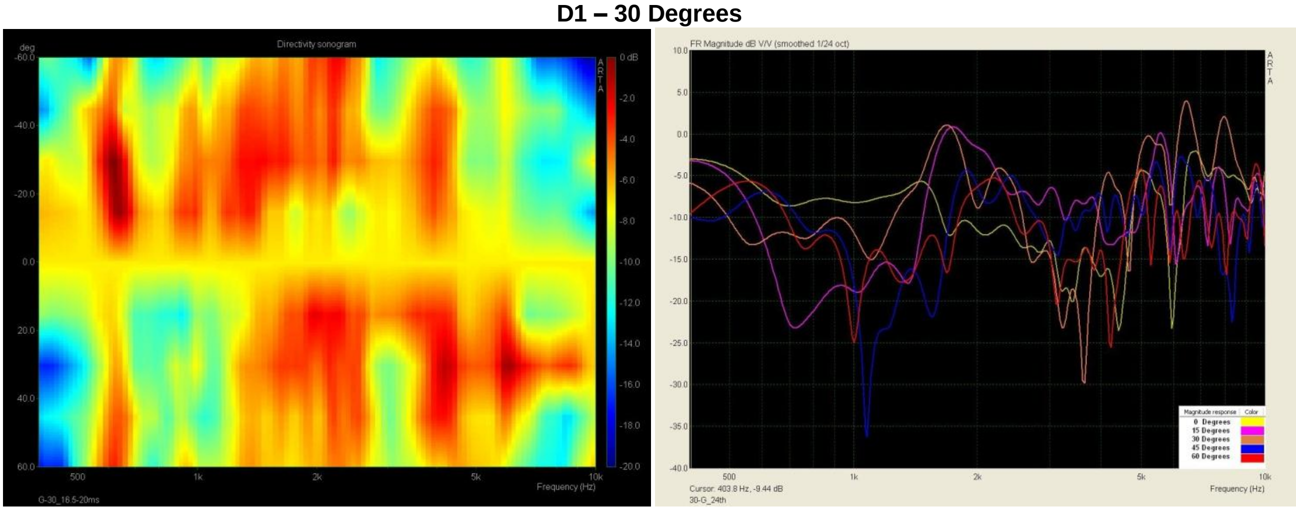
EB-Plate – 30 Degrees



QPRG – 30 Degrees

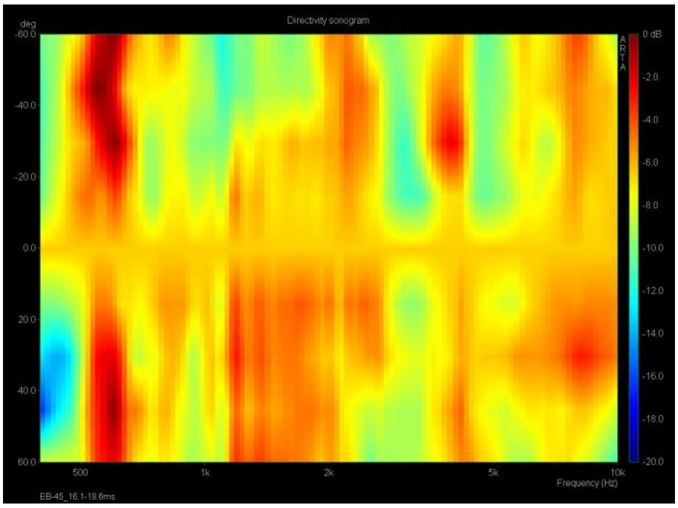


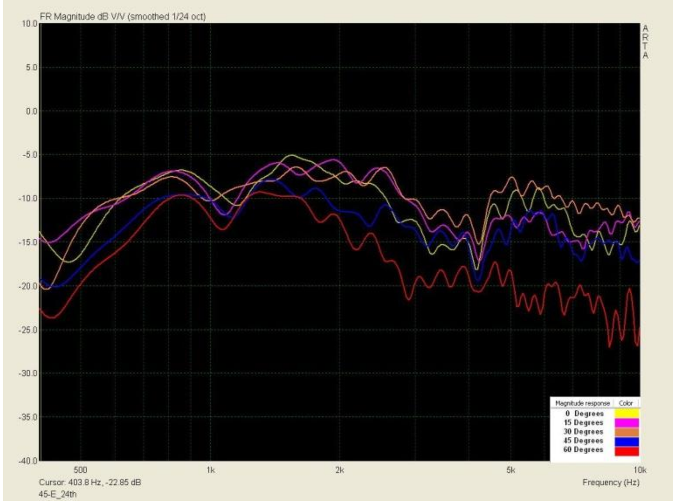
D1 – 30 Degrees



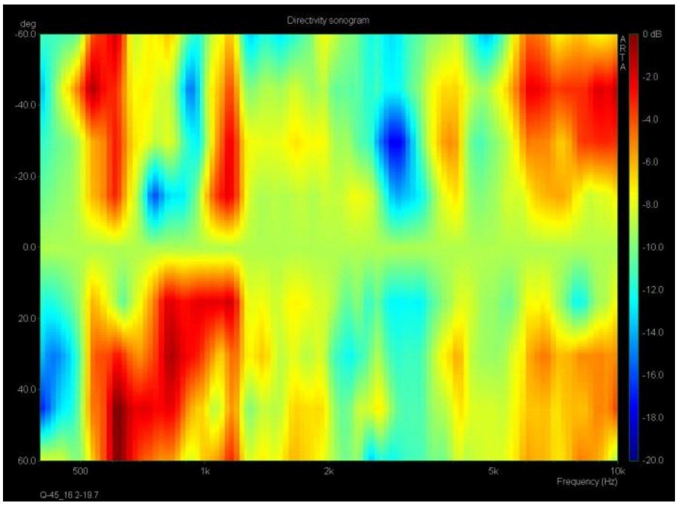
5.4 SPEAKER AT 45 DEGREE POSITION

EB-Plate – 45 Degrees

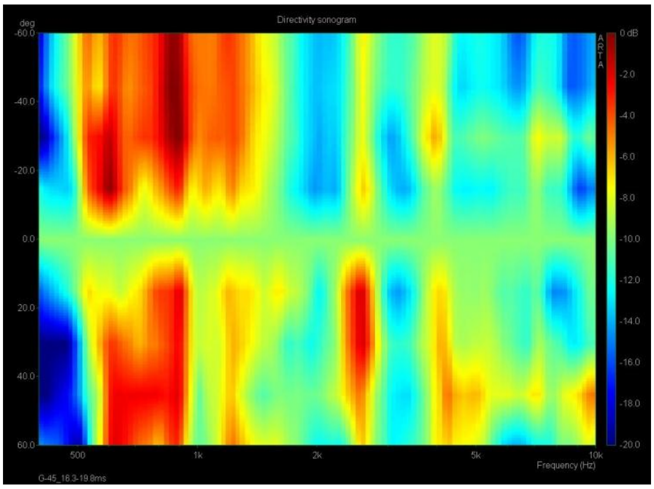


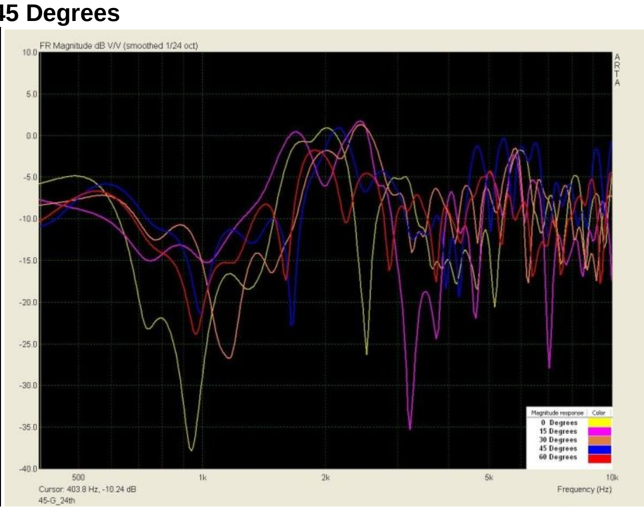


QPRG – 45 Degrees



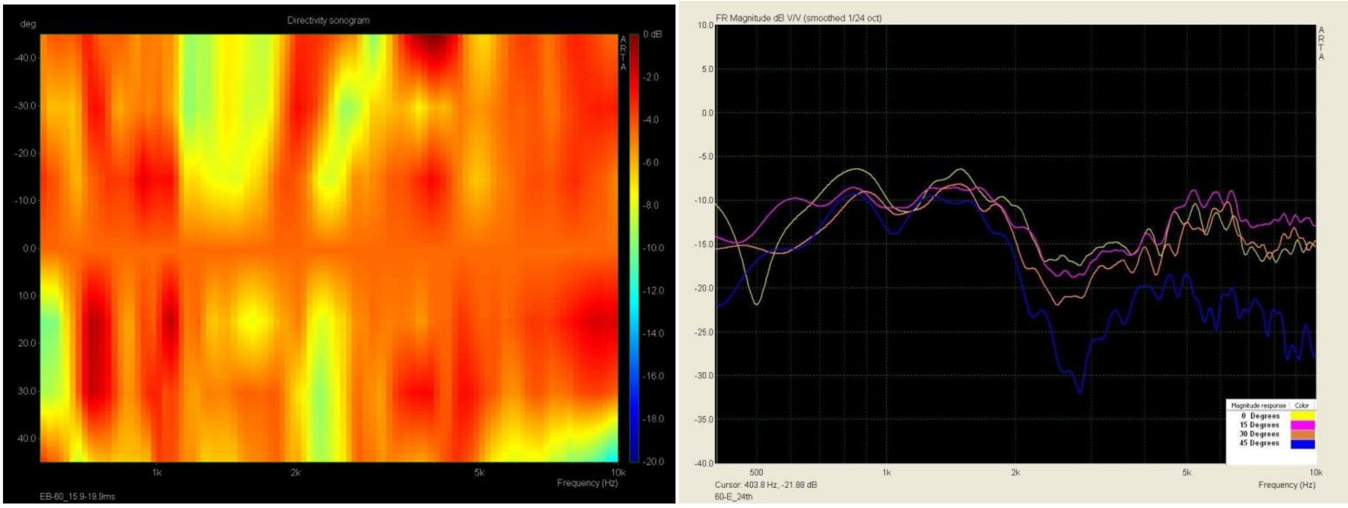
D1 – 45 Degrees



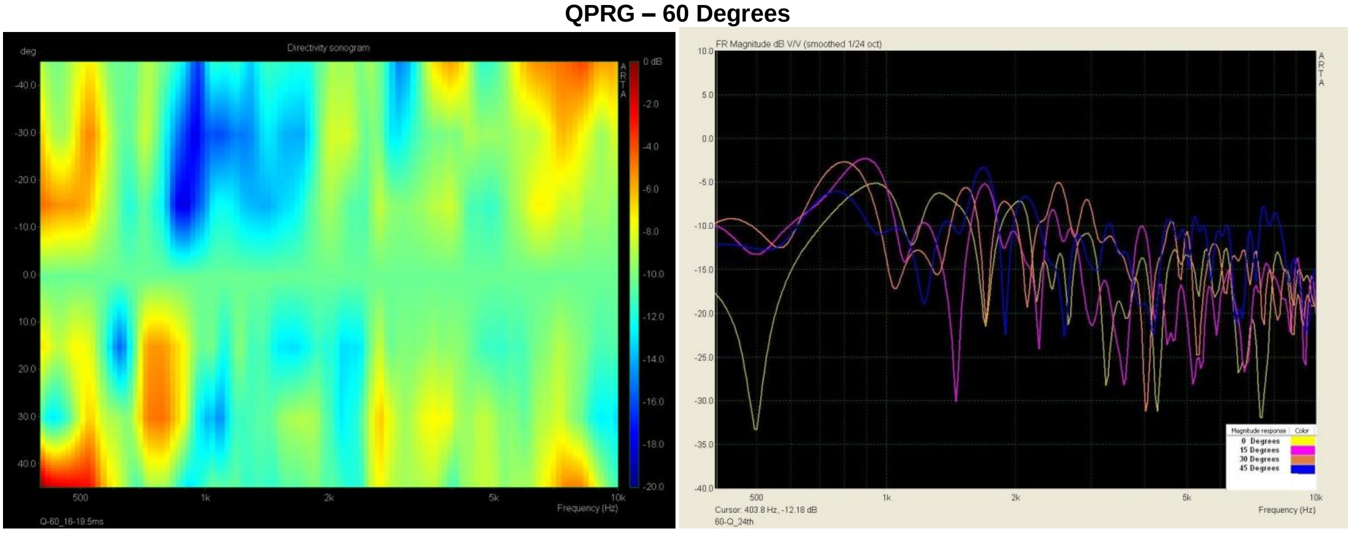


5.5 SPEAKER AT 60 DEGREE POSITION

EB-Plate – 60 Degrees



QPRG – 60 Degrees



D1 – 60 Degrees