DRIVE GRANULARITY FOR STRAIGHT AND CURVED LOUDSPEAKER ARRAYS

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1 INTRODUCTION

Loudspeaker systems built from arrays of sound radiators are a well established means to control directionality and increase power output, both essential features for sound reinforcement. The size of the individual elements and what pattern they are arranged in defines the intrinsic total radiation. For many systems the story ends there - a sufficiently useful directionality and power output is achieved through control of geometry and element properties alone. We'll refer to this type of array as 'geometric'.

Another class is the 'steered' array; here an acoustic aperture is formed from a densely packed array of elements. Each, or sometimes groups, of elements need to receive different electrical drive signals to produce a useful total radiation. The complexity of elemental signals within these systems varies widely but normally features at least gain, delay and IIR filters. The goal is often a frequency invariant far field beam pattern which can be achieved by changing the aperture size inversely with frequency via IIR filters[1]. The direction of the beam can then be altered by varying elemental delay. More advanced techniques employ FIR elemental filters derived via a least squares solution of the inverse problem[2].

The focus of this paper is the application of elemental FIR filtering to geometric arrays. Improvements to the intrinsic radiation have been demonstrated[3], however, this was for a fixed number of electrical channels per array cabinet. What happens to array performance when the number of channels available to the whole array is reduced? We start with a brief examination of straight steered arrays and show that granularity coarsening really amounts to an increase in elemental source size. Geometric arrays are discussed in more detail; a method to simulate various cabinet heights using smaller components is introduced followed by details of the experimental arrays used and how we might judge objective performance.

2 STRAIGHT ARRAYS

2.1 Definition

The definition of the straight electroacoustic line-array was first introduced by Olson[4] as a sum of a large number of simple point sources that are arranged equidistantly by a small separation on a line and driven with the same intensity. The directional characteristics of such array are given by,

$$R_{\alpha} = \frac{\sin\left(\frac{n\pi d}{\lambda}\sin\alpha\right)}{n\sin\left(\frac{\pi d}{\lambda}\sin\alpha\right)} \quad (1)$$

where d is the distance between sources, λ is the wavelength of the signal being reproduced and α is the angle between the normal of the array and the observation point. The acoustic pressure of

this array at an observation point x in a two dimensional space will be given by the product of the pressure on the axis (α=0) and the directivity function R_{α}.
A common loudspeaker source does not radiate in a spherical symmetric manner and therefore cannot be regarded as a simple point source but a source with its own directional properties. If all elemental sources are considered identical and placed in a straight line, the directional characteristics in the far-field can be given by the product of equation (1) and the directionality of one elemental source[5].

It can be therefore observed that the directional characteristics of a straight line-array as defined in [4] and [5] are dependent upon the source separation and the frequency being reproduced. When the source separation is below the limit set by spatial aliasing (d= λ/2), the width of the "beam" created by a straight line-array is inversely proportional to the frequency of the signal being reproduced.

2.2 Granularity Coarsening

The typical goals for steered array systems are a flat frequency response and constant directivity over a wide frequency range. Several attempts have been made to achieve these goal and in one proposed by Wal et al.[6] where a logarithmic spacing of sources was introduced. This proposal arranges sources equidistantly in the middle of the array and logarithmically on the outer part and a set of filters is designed to modify the input signals to be fed onto the loudspeakers. By using this approach a smaller number of sources are required to obtain a frequency independent beam width.
However, this approach may not be viable with a touring line-array loudspeaker. These loudspeaker arrays are generally comprised of identical modular cabinets containing a number of active independent sources to cover the audio spectrum. Modularity is a key feature of such systems since coverage requirements vary widely between deployments.

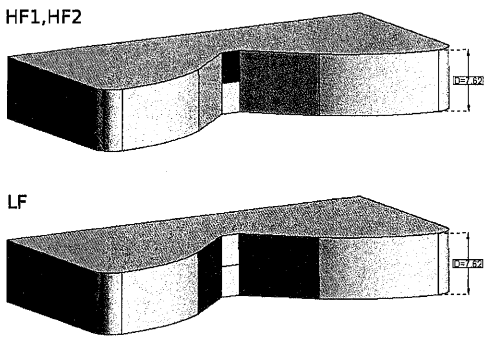
3 CURVED ARRAYS

3.1 Definition

We therefore focus our attention to arrays formed from identical modular cabinets The range of possible configurations of box size and source composition are theoretically infinite, however, drive units tend to come in discrete sizes. For mid and low frequencies 6, 8 and 12 inch drivers are typical, small high frequency direct radiators have a typical OD of 1.5 inches and horns driven with compression drivers are usually 3 to 6 inches high at the exit. Given these constraints, it is possible to define a reasonably representative set of configurations that reflect what can be achieved in practise.

3.2 Simulation

In order to efficiently simulate multiple configurations a single sub-element sized according to the smallest active source was modelled. A 3 inch high sub-element, comprising two full height LF pistons placed symmetrically around a twin central HF element. The HF element is split vertically into two pistons. Three dimensional balloon data for each of the sources is then obtained via BEM to be used in a CDPS direct field array model[7]. A steep 400 tap FIR based crossover was employed between the two bands at 1000Hz.



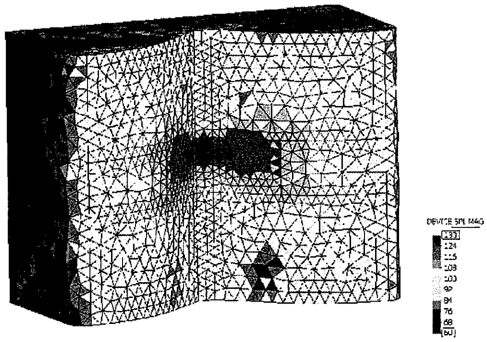


Figure 1 *Sub-Element active sources*

Figure 2 *HF1 flanked solutionsurface SPL*

To provide a more meaningful result the BEM model incorporates 6 inches of extra cabinet above and below to create 'flanked' data. This is an approximation to the boundary conditions experienced by the sub element when part of an array. More accurate results could be obtained by using 'positional' data[8], but for the purpose of this experiment the flanked approximation is tolerable.

3.3 Test Venues

Two test venues were defined. The first is a relatively simple one; a flat 40m long audience area with the array positioned at a reasonable height. This is a common setup and one where purely geometric arrays can be made to perform well without much effort – a low ratio of max to min array-audience path lengths.

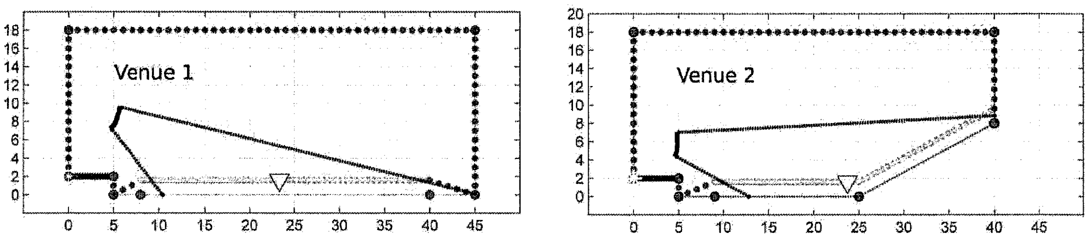


Figure 3 *Test Venue sections, green – audience, blue – stage, red – avoid.*

The second venue features a section of raked seating and the array is positioned quite low making it close to the stage.

3.4 Starting Points

To determine the shape of each test array in both venues the uniformly driven 6 inch model is subject to a splay angle optimisation with progressive shape constraint[9]. This curvature is used as a reference for the larger cabinet arrays. The integer spaced splay angles of the larger systems were visually adjusted to match the reference shape. In this manner we keep array shape as a constant within each venue throughout the experiment, although some small improvement can be obtained by unique splay optimisations for the larger box systems. Figure 4 shows the physical arrangement of the sub-elements for each array.

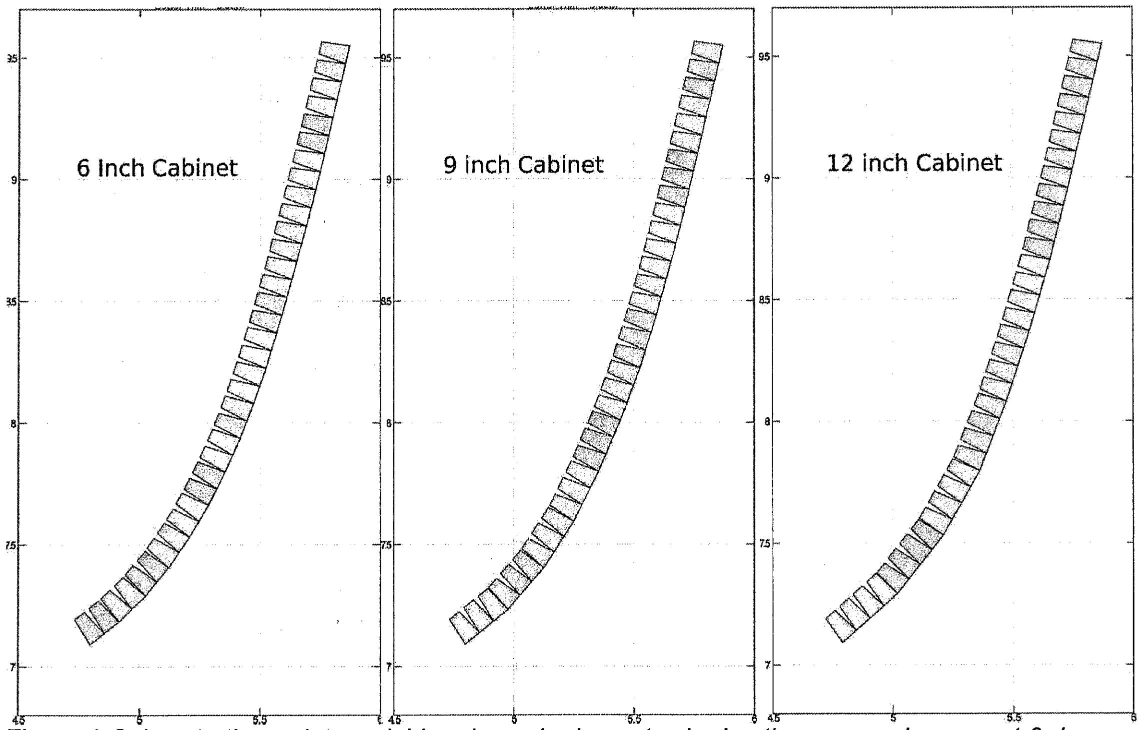


Figure 4 *Splay starting points, neighbouring sub-elements sharing the same colour are at 0 degree splay*

The starting point for drive granularity is determined by setting the nominal LF driver to 6 inches and HF driver to 3 inches. So, for the 12 inch box there are 4 HF and 2 LF channels, the 6 inch box has half this. Ideally the 9 inch box would be split into two LF channels but since we have an odd number of acoustic elements then this can not be. Instead we settle for a 9 inch LF and two 4.5 inch HF sources. Starting points are represented as the G4 configuration in Figure 5.

Direct comparison between the starting points for each box height is a little hampered by this, however, we are as concerned with how array performance changes relative to the starting point when granularity is coarsened as we are with differences between array shape smoothness.

3.5 Metrics

In order to establish a ranking between different granularities we can use the final values of the objective function used to optimise the transfer functions themselves. Three performance metrics are considered; 'target', 'leakage' and 'hard avoid', these are described in detail in[10].

Briefly, 'target' is a measure of difference between the result and a desired magnitude specification over the audience. In this experiment we have set the target to be a flat frequency response that falls linearly by 2dB from the first seat to the last seat – quite a challenging one. The 'target' value resembles the standard deviation in nature; the average absolute difference between the result and the desired over all frequencies and position. For venue 1 a tight specification of 0.5dB was used, for venue 2 a value of 1dB was selected.

'Leakage' is a measure of the difference between the average level throughout the audience and non-audience regions, a value of 25dB was used. Finally, 'hard avoid' is another form of 'leakage' but only considers a smaller non-audience region; this has been assigned to the stage area and was set at 35dB.

Each of the criteria is set as a goal and employed in a multi-objective optimisation algorithm with a number of constraint functions imposed on the iterate, these keep the resultant ideal complex transfer functions viable. The degree to which the goal has been met can be expressed as a percentage under or over achievement; we use these achievement descriptions in the results that follow.

3.6 Granularity Coarsening

From the starting point, configurations which had progressively fewer independent channels were determined for each array. The finest granularity (G4) represents what can currently be realised at a reasonable cost in cabinets with identical on-board amplifiers and DSP capabilities. Coarser configurations lend themselves to arrays where at least the processing and perhaps the amplification are separate from the cabinet, since there is commonality over box boundaries. The configurations are shown below in Figure 5.

Of note is configuration (G1), this is the coarsest granularity and was used to good effect to compensate for air absorptions losses[11]. This required a very modest number of independent channels and could easily be implemented on the hardware available at that time.

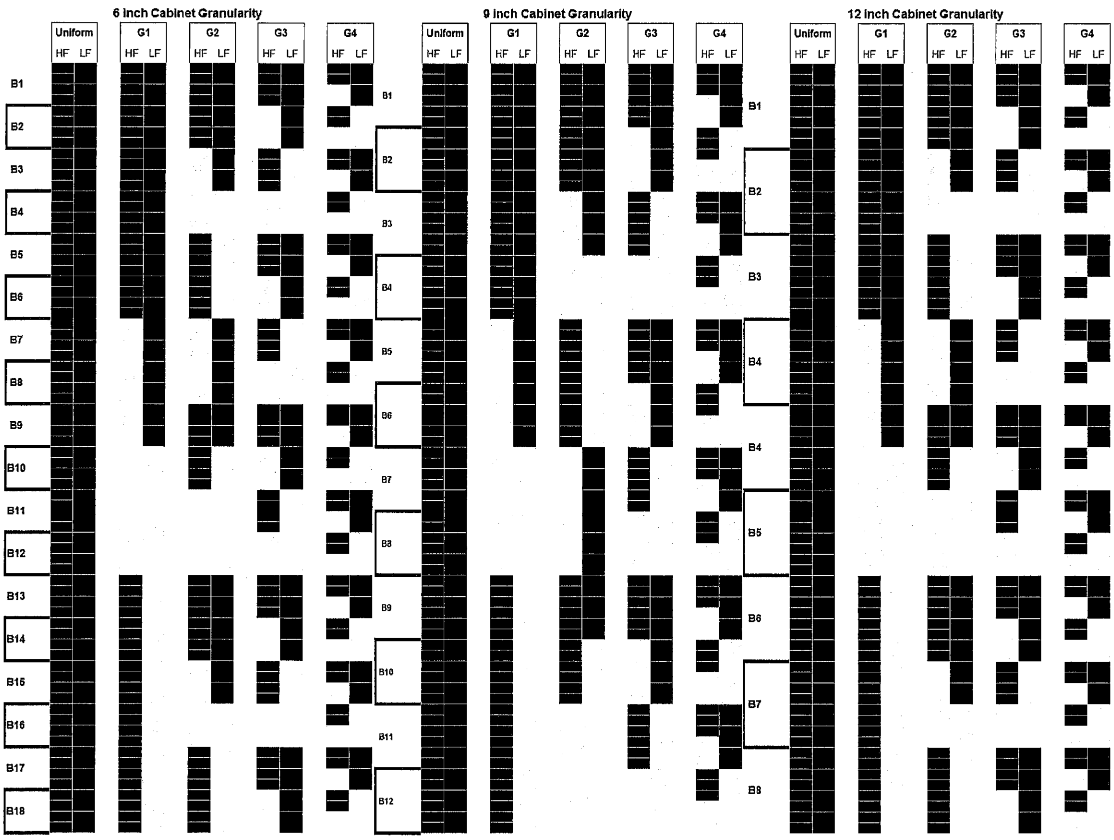


Figure 5 *Granularity configurations (G4 to Uniform) for each array type. Colour changes represent boundaries between independent channels*

4 RESULTS

The results from the above mentioned simulations are shown below as a function of each of the three performance metrics. Results from the intrinsic radiation are also included.

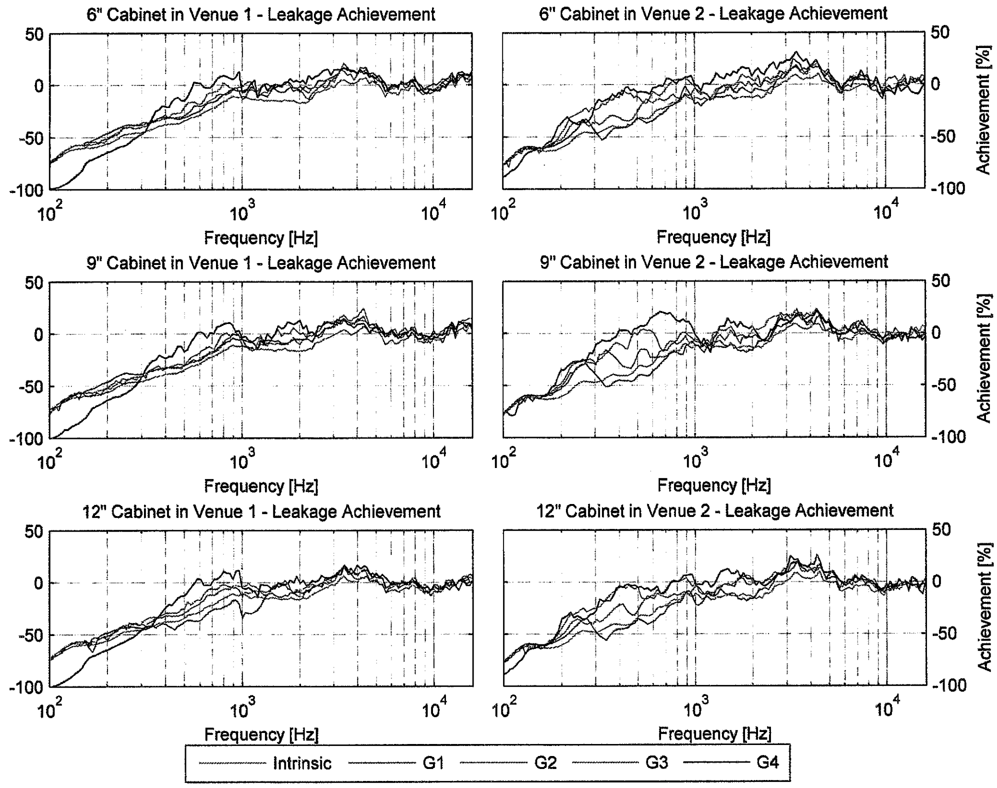


Figure 6 *Leakage achievement values*

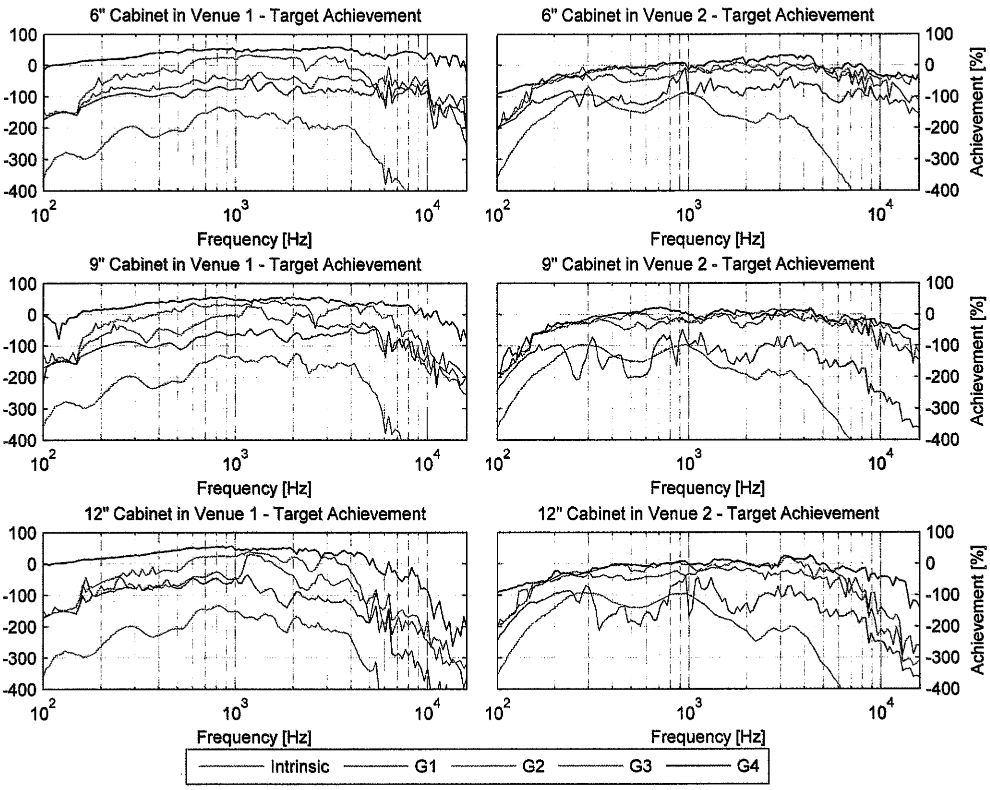


Figure 7 *Target achievement values*

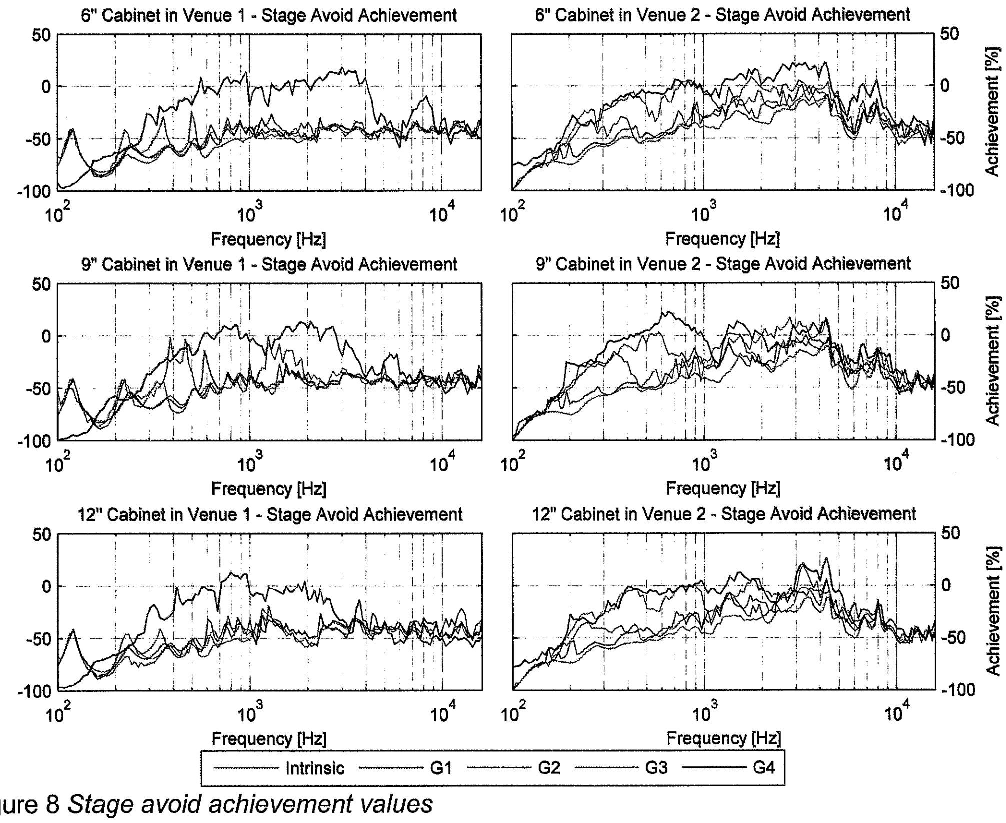


Figure 8 *Stage avoid achievement values*

5 DISCUSSION

The platform for the experiment was a software tool that is routinely used to deliver settings to numerically optimised arrays for real systems (with granularities around the G4 level). The optimisations were performed with uniform goal importance and the goal values chosen were close to the defaults for the real systems. Better results for each metric could be achieved if the others were ignored, ie single objective optimisations. However, this often results in unacceptable performance in the neglected metrics, so much so that the overall performance can be worse than the intrinsic uniformly driven one. By considering all goals in a balanced manner we can compare realistic differences between useful results.

We have also kept in all the additional constraints required to deliver filters that are realisable and measures to guard against the optimisation taking a numerically better but practically unhelpful path.

5.1 Leakage

For all venues, cabinet heights and granularities the performance converges to the intrinsic uniformly driven values at high frequencies. Midrange improvement is significant for most configurations but particularly in venue 2 and for fine granularity. The height of the cabinet does not seem to be an important factor given that each has a broadly similar pattern within the same venue.

5.2 Target

The 6 inch cabinet in both venues at the coarsest granularity is surprisingly good; the achievement values are close to those of finer granularity. For the 9 and 12 inch cabinets in venue 2, the 1dB target value is achieved rather well with granularities G2 to G4, only at high frequencies for the 12 inch cabinets does the performance degrade from the G4 starting point. A wider spread of achievement between granularities is evident in venue 1 where the target value was more difficult (0.5dB), this is especially so for the 9 and 12 inch cabinet

Of particular interest, because it embodies what is often a design goal for many systems[12], is the 12 inch cabinet in venue 1. Due to its “flat” arrangement a so called isophasic flat wavefront is generated over the full height of the cabinet. It can be observed, however, that the flat wavefront approach performs poorly compared to more curved arrays (venue 2) at high frequencies.

5.3 Stage Avoid

In all cases only the finest granularity offers a significant improvement in performance above the intrinsic uniformly driven result, especially true for venue 1. As might be expected, the high frequency achievement converges to the intrinsic values as it did for ‘leakage’. The 9 inch cabinet has poorest performance and in all results, refinement in granularity does not always provide a significant increase in performance.

6 CONCLUSION

At high frequencies, arrays with a smoother shape perform better at meeting a desired target over the audience region than less smooth ones, even when the rougher array has a finer drive granularity

High frequency leakage performance converges to the intrinsic uniformly driven result and is not dependent on granularity or array smoothness.

Useful improvement in leakage at low and medium frequencies, particularly on small targeted areas, requires the finest granularity. Arrays with coarser granularity all perform similarly, i.e. there is a threshold in granularity below which refinements result in marginal performance gains.

When good agreement to the desired audience magnitude specification is desired, successive refinements in granularity result in proportional increases in performance.

7 REFERENCES

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