



HAL
open science

Investigating properties of random sound source constellations

Andor Tamos Fürjes

► **To cite this version:**

Andor Tamos Fürjes. Investigating properties of random sound source constellations. Forum Acusticum, Dec 2020, Lyon, France. pp.883-888, 10.48465/fa.2020.1081 . hal-03233775

HAL Id: hal-03233775

<https://hal.science/hal-03233775>

Submitted on 26 May 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

INVESTIGATING PROPERTIES OF RANDOM SOUND SOURCE CONSTELLATIONS

Andor T. Fürjes

aQrate Acoustics Ltd., H8083 Csákvár, Hungary
furjes.andor@aqrate.hu

ABSTRACT

It is not uncommon in acoustics practice that one has to predict the effect of clusters of sound sources, even if position, aiming, exact power or directionality is not known for each instance at any moment. Some examples are road traffic (line), crowd noise or construction site noise (surface), stage monitor loudspeakers or instruments (volume). More abstract examples are diffuse (random) reflections off boundaries.

In a general formulation clusters of emitters that do not interfere with each other can have either random or definite (A) power, (B) directionality, (C) aiming and (D) position along a (1) trajectory (e.g. road), (2) a surface (rectangular or spherical), or (3) within volume (a rectangular or spherical).

The paper presents results of a series of theoretical experiments to find out if there are any characteristic properties of such constellations in the near or far fields.

1. INTRODUCTION

Many years ago I had the task to do noise mapping of an open air summer festival. There were several stages, each had its own loudspeaker systems aimed at their audience areas. I did the calculations as the FOH (front of house) loudspeaker systems are determinate in type, directionality, aiming, etc.

However, there was no data available on how loudspeakers on the stage were configured, because within each stage for each performance the layout and the types of sound sources were different. Back then I simply estimated the total sound power for each stage and assumed a single spherical virtual source for the stage.

For the crowd noise I assumed that it is negligible compared to the sound power of the sound systems.

Finally, even if I had nicely colored noise maps, I had to state, that much of the calculations is based on approximations and temporarily noise levels can change even +/-10 dB in any direction at large distances due to atmospheric irregularities.

A similar set of problems is about construction noise: number, position, instantaneous sound power, aiming of noise sources can be estimated, statistically and spatially averaged, and finally summed. Even then, results are more fictitious than exact.

Calculation of traffic noise has similar problems on how vehicle specific deviations (e.g. directional behavior, total sound power) affect overall results and uncertainties.

Also common in the problems above is, that sound sources are usually taken as omnidirectional monopoles, while real sound sources have directional behavior and hence a random configuration of sound sources are surely affected by aiming and directionality of possible sources.

Later I did calculations for simplified geometrical schemes: sphere volume, sphere surface, rectangle volume, rectangle surface. A set of sound sources were distributed randomly along volume or surface, where each sound source had a definite (e.g. inward or outward) or random aiming and each source had a definite or random axisymmetric directional radiation pattern. By repeating these tests, average of results from possible realizations outlined unique characteristics.

The problem formulation is illustrated in Figure 1.

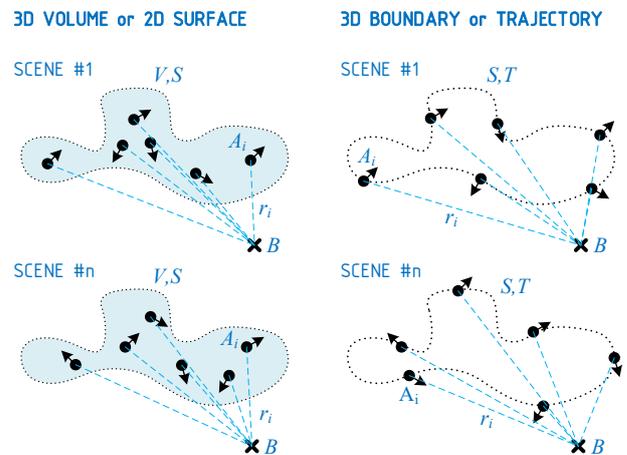


Figure 1. General problem formulation scheme. For each scene A_i is the i -th virtual point source with individual aiming and directional characteristics, B is the observation point, V is the volume, S is the surface or boundary, T is the trajectory. Geometrical constraints are constant for each scene, results are corrected for total emitted power of sources.

This approach is actually a Monte Carlo method of random constellations of sound sources. By itself such an investigation is not new (see e.g. [1], [2]), but the general formulation and the use of directional behavior seems unexplored.

This paper presents the theory and calculation results of a series of theoretical experiments of the summed sound field of sets of random constellations of sound sources.

2. INITIAL THOUGHTS

For any set of sound sources, at first we aim to find characteristic features, such as variability and average sound pressure level as a function of distance along an axis.

The following factors surely affect the overall results:

- number of sources
- summation by power for incoherent sources
- variability in radiation power
- variability in directionality of each source
- variability of aiming of each source
- variability in position.

Variability in position can mean that sources are fixed, but their possible positions are limited to an area or a volume or a trajectory. Variability can mean also, that sources are moving, but since both positions and trajectory can be assumed to be random, this random movement of sources is thought to be equivalent as a series of random but fixed positioned sources ('stop motion' or sampled motion). If speed of movement is not random, the spatial uniformity of sources can be transformed to match the non-uniform distribution of occurrence (see example in Section 7).

Here we evaluate the following sets of spatial distributions:

- spherical 3D constellations: sources can be within a spherical volume of a sphere or along the surface of the sphere;
- rectangular 3D constellations: sources can be within a rectangular volume of a sphere or along the surface of a rectangular boundary;
- constellation along trajectories: sources can be along a trajectory (line, circle or any set of 1D segments).

For the sake of simplicity, we assume the followings:

- i. exact position of sources is random (based on uniform distribution), only spatial limits are known;
- ii. position of sources for a single constellation is fixed (system is time invariant or represents a suitably narrow time slice, e.g. instantaneous sample);
- iii. observation points are always assumed to be in the far field of any source (only far-field behavior is considered and a single distance-independent directivity characteristics can be used);

- iv. directional characteristics of each source is axisymmetric (sources can be described by the main direction and a set of form factors);
- v. radiation by wave propagation is ensured by a time-invariant and isotropic media (e.g. no refraction, no reflection in any direction);
- vi. phase-shift due to finite speed of propagation is omitted, because of incoherent sources and because mainly effects of directional behavior is of interest.
- vii. there are no obstructions of radiation (free field with no diffraction and reflection);
- viii. sources do not interact (i.e. sources do not affect randomness of variables);

Please note, that in a way, due to simplifications above, this can be only a macroscopic view of reality. However, such simplifications are common for large size models (e.g. environmental noise of multiple sources).

3. SINGLE SOURCE DESCRIPTION

Sound source constellations are assumed to consist of incoherent virtual point sources. The effective sound pressure field p_i of the i -th virtual point-source with an axisymmetric radiational pattern located in A at position B can be written in the form:

$$p_i = \frac{W_i}{r_i} D_i(\varphi_i) \quad (1)$$

where W_i describes source strength, $r_i = |A_i B|$ is the distance from the source, and $D_i(\varphi_i)$ is the directional term:

$$D_i(\varphi_i) = \sum_{k=0} a_{i,k} \cdot \cos(k \cdot \varphi_i). \quad (2)$$

where a_k is a k -th order form factor.

Eq. (2) is a series of cosines, because any arbitrary axisymmetric directional characteristics is an even function, which can be transformed using the even Fourier-series.

For practical reasons directional behavior is limited to the second order terms:

$$D_i(\varphi_i) = a_{i,0} + a_{i,1} \cos(\varphi_i) + a_{i,2} \cos(2 \cdot \varphi_i) \quad (3)$$

because these three terms can describe the most common directional characteristics. This limitation also helps to simplify calculations:

$$D_i(\varphi_i) = a_{i,0} + a_{i,1} \cos(\varphi_i) + a_{i,2} [2\cos^2(\varphi_i) - 1] \quad (4)$$

since $\cos(\varphi_i)$ can be easily calculated:

$$\cos(\varphi_i) = \frac{\overline{A_i B} \cdot \vec{v}_i}{|A_i B|}. \quad (5)$$

if \vec{v}_i is the unit vector representing the aiming of source i .

Using $(a_0; a_1; a_2)$ notation, $(1; 0; 0)$ is an omnidirectional monopole, $(0; 1; 0)$ is the dipole, $(0; 0; 1)$ is the lateral

quadrupole and (0.5;0;0.5) is the longitudinal quadrupole directivity. Some examples are shown in Figure 2.

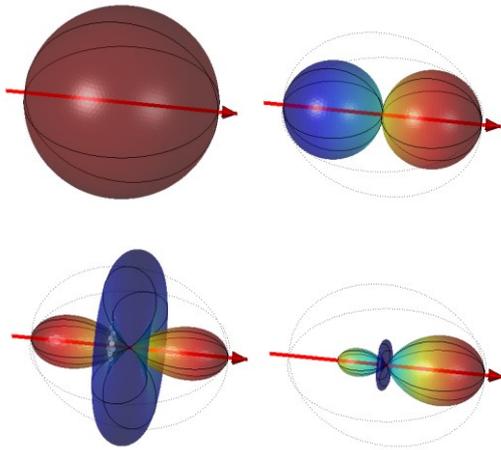


Figure 2. Directional balloons of (1;0;0), (0;1;0), (0;0;1) and (0.25;0.25;0.50) characteristics. Color blue denotes negative values.

Total emitted power of an axisymmetric directional source is proportional to the random energy efficiency (RE), which is calculated from the directional characteristics (see e.g. [3]):

$$RE_i = \frac{1}{2} \int_0^\pi \sin(\varphi) \cdot D_i^2(\varphi) d\varphi. \quad (6)$$

Figure 2 shows RE as a function of a_0 and a_1 . For a normalized expression, one may assume condition $a_0+a_1+a_2 = 1$ in order to have $D(\varphi = 0) = 1$ (on-axis), so that $a_2 = 1-(a_0+a_1)$.

An omnidirectional (1;0;0) source has $RE = 1$, and other ($a_0; a_1; a_2$) is the region of interest has $RE < 1$ (see Figure 3). $RE < 1$ means, that for the same on-axis response, the total emitted power is less, than of an omnidirectional source (which is obvious).

Radiated power must be normalized so that radiated power does not depend on directional characteristics. Normalization means that when calculating the sum of powers, the power of each source must be corrected so

$$W'_i = \frac{W_i}{\sqrt{RE_i}}, \quad (7)$$

and

$$p'_i = \frac{W'_i}{r_i} D_i(\varphi_i) \quad (8)$$

Alternative forms of expressing these corrections are the directivity index

$$DI_i = -10 \cdot \log_{10} RE_i. \quad (9)$$

the distance factor:

$$DF_i = \sqrt{RE_i}. \quad (10)$$

or the directivity factor $Q_i = 1/RE_i$.

Properties of usual characteristics is listed in Table 1.

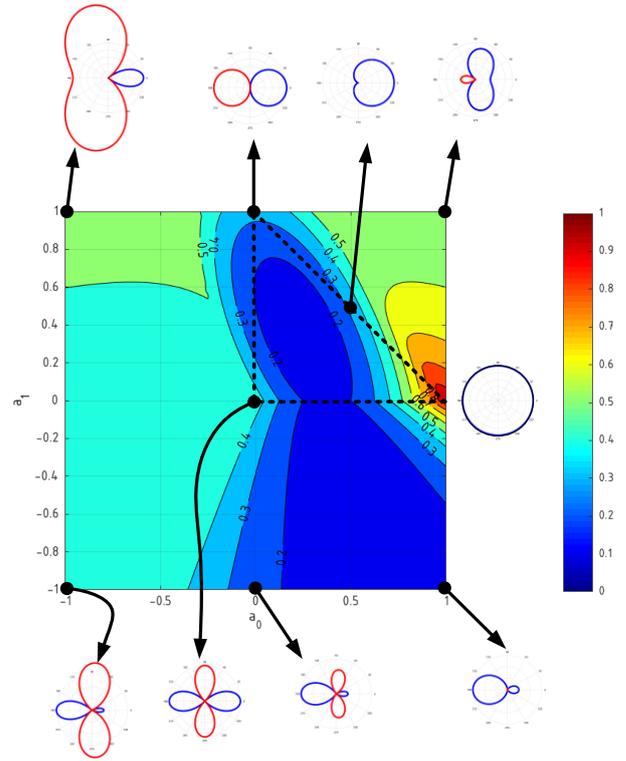


Figure 3. Random energy efficiency (effect of directional characteristics on emitted power relative to the power of an omnidirectional source) for different form factors. Only combinations within the dashed triangle are used in practice. Combinations outside the triangle are mostly theoretic. Color blue in polar plots denotes positive values.

D			name	RE	Q	DI	DF
a_0	a_1	a_2		-	-	dB	-
1,00	0,00	0,00	omnidirectional	1,00	1,00	0,0	1,00
0,00	1,00	0,00	dipole (gradient, figure of 8)	0,33	3,00	4,8	1,73
0,00	0,00	1,00	lateral quadrupole	0,47	2,14	3,3	1,46
0,50	0,00	0,50	longitudinal quadrupole	0,20	5,00	7,0	2,24
0,50	0,50	0,00	cardioid	0,33	3,00	4,8	1,73
0,25	0,50	0,25	2nd order cardioid	0,13	7,50	8,8	2,74

Table 1. Overview of the most common directional characteristics.

4. METHOD

The method of this experiment is to set up randomized scenes repeatedly and see if average of results is converging. The number of sound sources are fixed for a series of scenes, but positions, power, aiming and even directional characteristics can be randomized.

In order to make results comparable, the summed field of sources is normalized to the total source strength at point B:

$$\tilde{p}_B = \sqrt{\frac{\sum_{i=1}^N p_i'^2}{\sum_{i=1}^N W_i'^2}}. \quad (9)$$

5. SPHERICAL CONSTELLATION

A scene of sources along a spherical boundary is shown in Figure 4. Aiming of sources can point inward or outward, and aiming can be randomized (normal or uniform distribution), as illustrated in Figure 5.

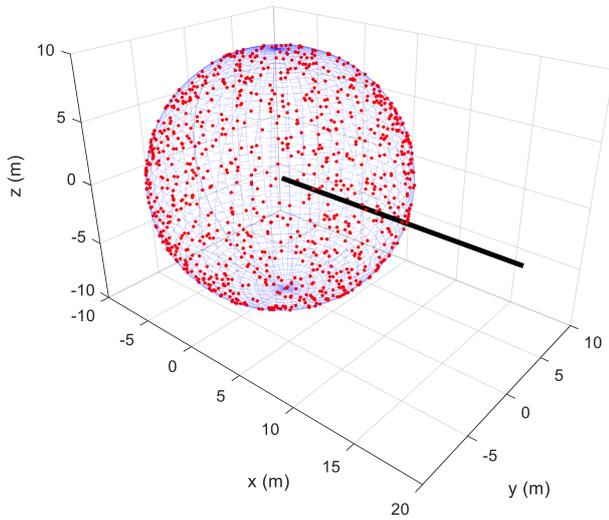


Figure 4. Random sources along a spherical boundary. Thick black line is the axis of observation.

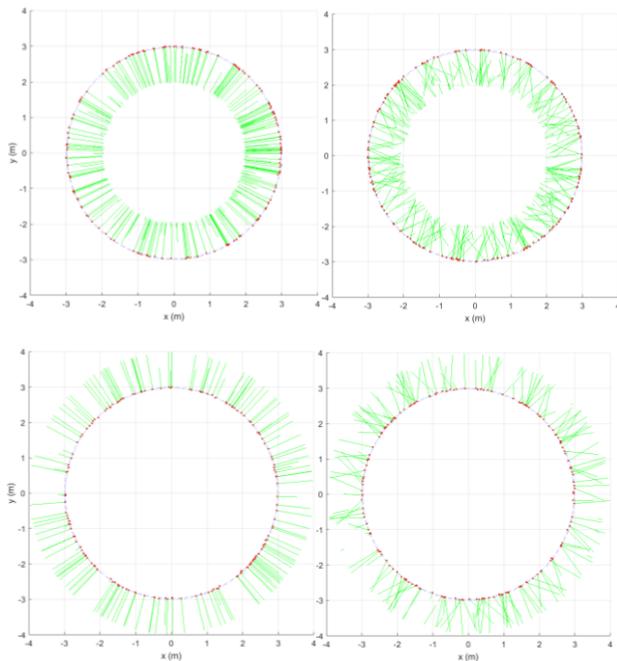


Figure 5. Possible aiming of sources along a spherical boundary. Aiming can point inward (upper row) or outward (lower row) and aiming can be randomized (right column).

Observation points are taken along (1;0;0) axis. Results of all experiments are stored and finally $10 \cdot \log_{10}(\text{median}(\hat{p}_B^2))$ is plotted. For the sake of readability distance is also plotted in logarithmic scale. An example of a series of runs is shown in Figure 6 for a $\varnothing 20$ m sphere.

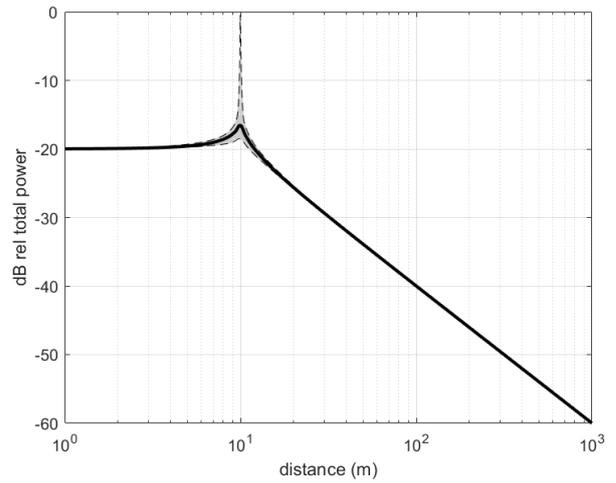


Figure 6. Sample of a result for random omnidirectional sources along a 10 m radius spherical boundary.

As one can see, highest variance is at where the observation axis hits the boundary and beyond that point the set of sources behave exactly as a single source of the same power. It is less obvious, however, that within the boundary, SPL is almost constant.

Results of different settings of this scene are shown and compared in Figure 7.

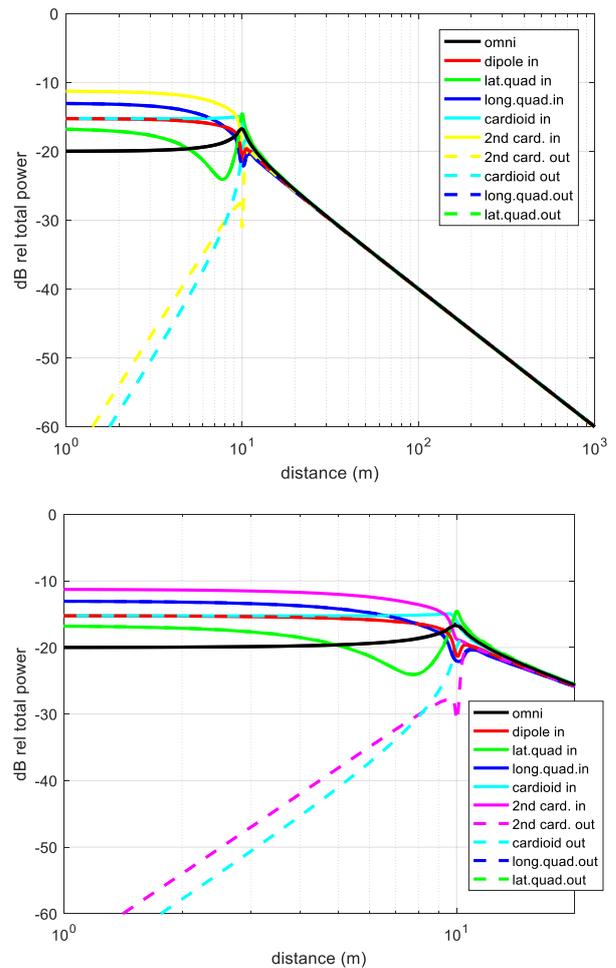


Figure 7. Results of sources along spherical boundary.

According to the results, if sources point inward, SPL at center depends on the radius of the sphere and the average distance factor of sources, and expected SPL near the boundary is characteristic to average directivity.

A scene for the volumetric sphere constellation is illustrated in Figure 8, results in Figure 9.

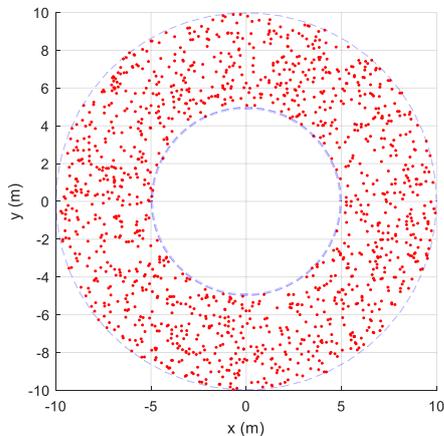


Figure 8. Volumetric sphere constellation ($R_1=5$ m, $R_2=10$ m, slice between $z = -1.0\dots+1.0$ m is shown).

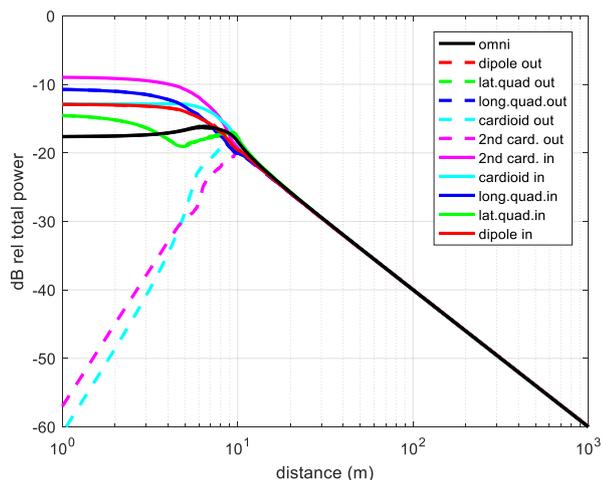


Figure 9. Results of a volumetric sphere constellation ($R_1=5$ m, $R_2=10$ m).

If aiming is randomized, as expected, effect of directionality of each individual source will diminish (see Figure 10).

6. RECTANGULAR CONSTELLATION

A rectangular constellation is characterized by its length, width and height. Sources can be positioned along the boundary or within the volume, aiming in or out.

Running different scenarios gives also characteristic results. Results of constellations along a $20\times 20\times 20$ m sized boundary (see Figure 11) with stable aiming are shown in Figure 12.

Results of the omnidirectional sources are analog to diffuse field conditions in a rectangular room.

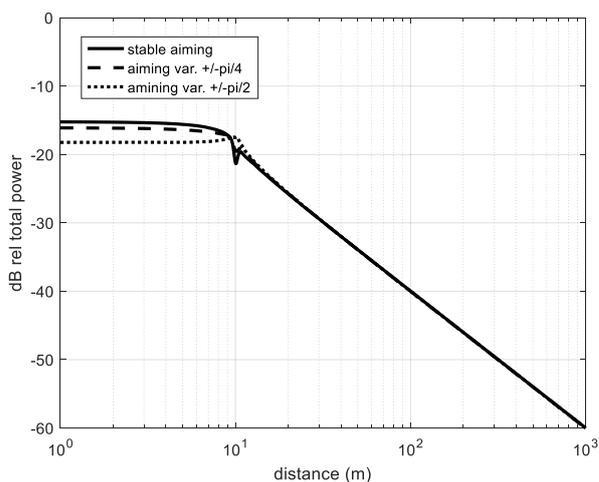


Figure 10. Randomizing aiming diminishes effect of directivity (dipole sources along a $\varnothing 20$ m spherical boundary).

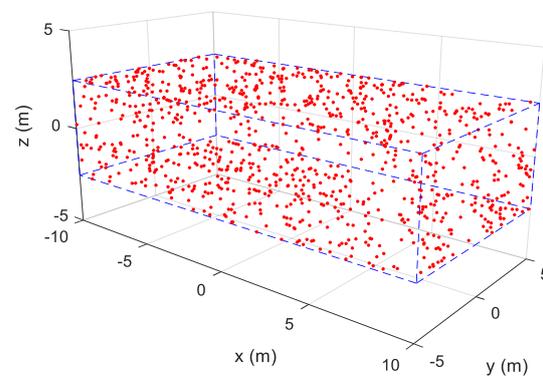


Figure 11. Random sources along a rectangular boundary.

If ratios (height, width) are changed, results change accordingly. A $20\times 20\times 1$ m boundary may be analog to a parking lot (see Figure 13), while a $1\times 100\times 1$ m boundary may be analog to a 100 m long road for example (see Figure 14).

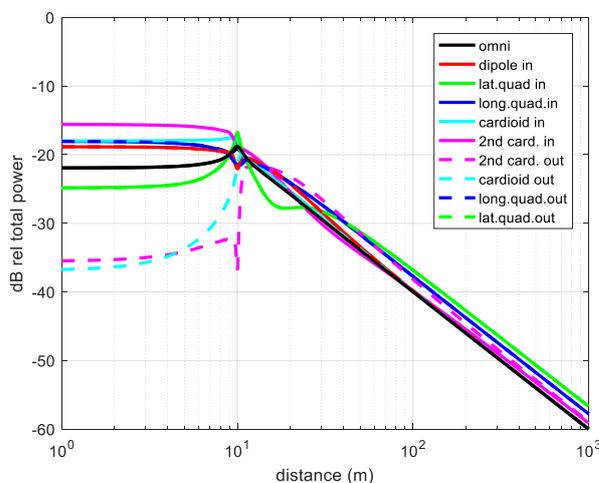


Figure 12. Expected SPL vs. distance from the center of a $20\times 20\times 20$ m boundary if aiming is stable.

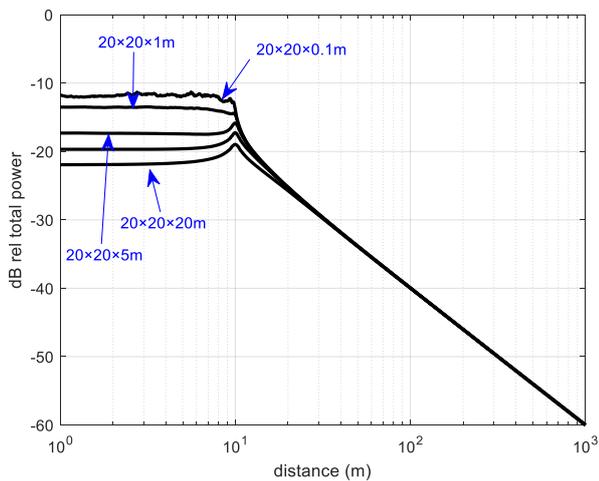


Figure 13. Expected SPL vs. distance from the center of a rectangular boundaries of different sizes if aiming is stable.

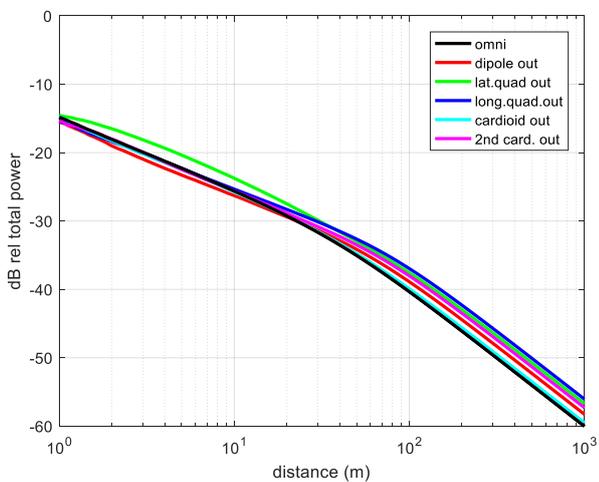


Figure 14. Expected SPL vs. distance from the center of a $1 \times 100 \times 1$ m rectangular boundary if aiming is stable.

Based on preliminary results it may be suspected, that independently from power of sources, directionality can have a significant effect also in the far field of such constellations.

7. TRAJECTORY

Sources can be randomly positioned along a trajectory or a set of trajectories (e.g. a road map), where probability distributions of positioning can be set to characterize chances of occurrence or speed of sources at given sections of the trajectory.

Figure 15. shows a result of a map of the Hungaroring. Geometry is taken from public maps. Sources are positioned along the raceway by estimating local speed based on curvature of the trajectory and average speed of past race events. Color map is scaled to the total power of the sources.

Although this example is merely theoretical (input data is based on estimations), the method seems viable not just for theoretical purposes.

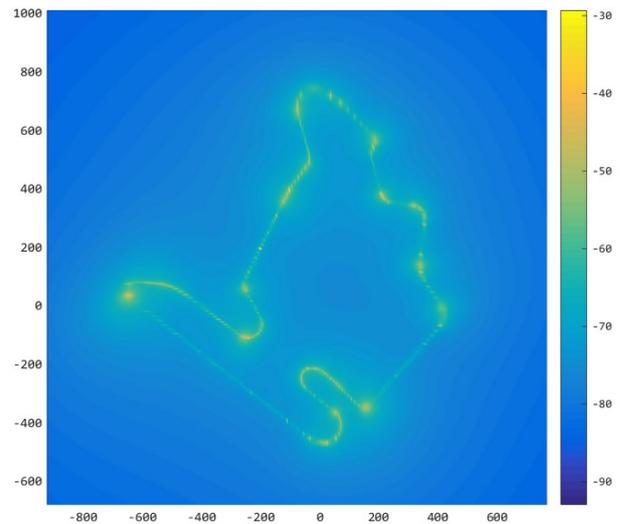


Figure 15. Projected mapping of Hungaroring based on raceway geometry as a trajectory of random source constellations and estimated local probabilities based on curvature and average speed.

8. SUMMARY

While it may seem loosely formulated, random constellation of sources modelled using the Monte Carlo method, show characteristic features beyond theoretically obvious situations.

Due to the general formulation, aiming and directional characteristics can be both randomized for practically any geometry. Preliminary results suggest, that typical aiming and directional behavior of sources have a significant effect on both near field and far field of such constellations.

Basic theoretical scenarios may be interesting to other disciplines (e.g. astrophysics) as well.

9. REFERENCES

- [1] Z. Haron, K. Yahya, "Monte Carlo analysis for prediction of noise from construction sites", *Journal of Construction in Developing Countries*, Vol. 14, No. 1, 2009
- [2] I. C. M. Guedes, S. R. Bertoli, J. Montalvão, "Monte Carlo simulation of traffic noise dynamics at a bust stop based on real sound signals", *Proc. Mtgs. Acoust.* 28, 040005 (2016)
- [3] Ray A. Rayburn, *Eargle's Microphone Book*