# Control of Radiation Directivity Applying Independent Element Dodecahedral Loudspeaker

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*Abstract* – **Control and synthesis of sound source directivity have a significant position in modern acoustics. For this purpose, special sound sources that consist of independent element loudspeaker array are used. Sound source analyzed in this paper is a loudspeaker array in the form of dodecahedron. To generate different directivities, the loudspeaker array is fed independently with a few characteristic sets of signals. Special setup was established for radiation directivity measurements. For analyzing and presenting the results, a MATLAB application is developed. The measured directivities obtained by feeding of some of the loudspeakers with particular signals show interesting patterns of radiation.**

*Keywords* – **Sound source, loudspeaker array, dodecahedron, radiation directivity, swept sine technique.**

## I. Introduction

Radiation directivity pattern is one of the most important properties of a real sound source [1], [2]. It reflects source's interaction with the environment and therefore it is a significant parameter in various acoustics researches. A sound source can generally be characterized by three properties: timbre related to spectral and temporal attributes, intensity, and directivity providing spatial information on the sound radiated from the source [3]. Today's loudspeaker systems can faithfully reproduce the sound tone (timbre) and intensity, but they have typical directivities that are significantly different from the directivities of natural sound sources [4]. Therefore, there is a need for simulating (synthesizing) directivity characteristics of the real sound sources [5]. This can be realized using the three-dimensional sound sources, such as dodecahedral loudspeaker [6-9].

Another problem with modern sound sources comes from the requirement for omni-directivity. Sources are typically not omni-directional in the whole frequency range, but only at lower frequencies [4], [5]. That gives importance to researches dealing with radiation directivity control.

In this paper, a sound source based on a loudspeaker array in dodecahedron form is used for radiation directivity control. Method for analyzing the radiation directivity is partially developed in earlier researches [4], [5], but it is modified here in order to enable using all twelve channels independently. Special attention is paid on establishment of unique, easy to use, measurement system, and synthesis of basic radiation directivity patterns.

## II. Measurement System

The computer-based measurement system was established especially for the purpose of radiation directivity measurement. It consists of a computer (laptop), M-Audio ProFire 610 audio interface (sound card), M-Audio Fast Track Pro audio interface, twelve-channel audio amplifier, spherical sound source with independent elements in the form of dodecahedron (Fig. 1), condenser measuring microphone with preamplifier, and power supply.

Fig. 1. Sound source with independent elements (loudspeakers) in the form of a dodecahedron

Since the dodecahedral loudspeaker array consists of twelve loudspeakers, independent signals were fed via two audio interfaces to every of these twelve channels. Eight channels of M-Audio ProFire and four of M-Audio Fast Track Pro provide the needed twelve channels, which could be controlled independently. The diagram of the measurement system is shown in Fig. 2. Due to the different characteristics of the interfaces, setting up of the system was more complicated, and a latency problem was inevitable. The problems were resolved by applying special calibration method that includes measuring of impulse responses for both sound cards independently and determination of latency difference

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between two impulse responses. Based on this information, silence of appropriate duration is automatically added before the measurement signal with smaller latency. In this way, signals from both sound cards have the same latency.

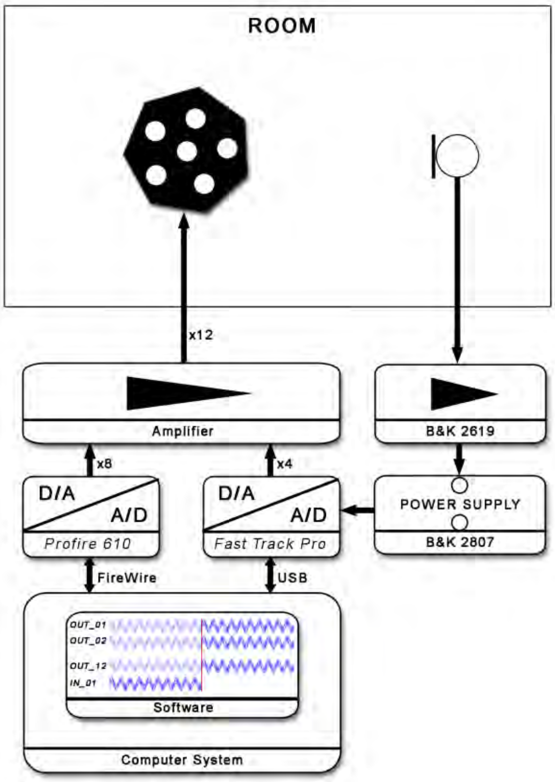


Fig. 2. Measurement system

Also, the measurement system has basic signal control options implemented in every channel, such as amplitude regulation and phase inversion. This provides a lot of combinations that could be used for achieving the wanted characteristics of radiation.

## III. RADIATION DIRECTIVITY MEASUREMENT

The measurements were carried out in pseudo anechoic conditions. Distance to the first obstacles was greater than 1.5 meters, so difference between direct sound and first reflection was about 10 ms, which allows us to identify and cut off all reflections, and analyze only direct sound. Microphone and sound source were placed on the same height and the distance between them was 1 meter.

Measurement process is based on swept sine technique [10], [11]. In our earlier research, it has been shown that this technique is more reliable than some other tehnuiques (like MLS technique) [12], [13]. The excitation signal used in this technique is so called swept sine or sweep. It represents a sine signal with frequency varying in time, e.g. linearly (linear sweep) or exponentially (logarithmic sweep). Swept sine technique is considered to be immune to some disturbances such as time variance or non-linearities [10], [11]. Also, one of its advantages is that precise synchronization between the clock applied for the test signal reproduction and recording of the response during the measurement is not required [12]. In the present research, an excitation swept sine signal of duration of about 24 seconds with frequency range from 10 Hz to 22 kHz sampled at 44.1 kHz is used.

Three excitation combinations are utilized. For the first one, six loudspeakers from one half of the sphere are fed with the same sweep signal, and the other six with opposite phase of the same signal. For the second and the third one, two opposite loudspeakers on the sphere are fed with corresponding signals. In one of the configurations, loudspeakers are fed with the same signals in phase and in the other one with same signals, but in opposite phases.

The radiation directivity is measured only in horizontal plane with resolution of $10^{o}$, so there are 36 impulse responses for each excitation combination. Measurements were performed in a way that the microphone was fixed, and sound source was rotated around its horizontal axis. Processing of the extracted part of the impulse response (free of reflections) is performed in the frequency domain, which is based on FFT and determination of impulse response spectrum. After determination of spectrum, next step is determination of direction of maximal radiation (reference axis), which is used for normalization and presentation of directivity patterns. Using this kind of processing, radiation pattern can be obtained for many different frequencies. Actually, the maximum number of frequencies (the frequency resolution) depends on the length of the extracted impulse response containing only direct sound. Summary of impulse response processing is given in Fig. 3.

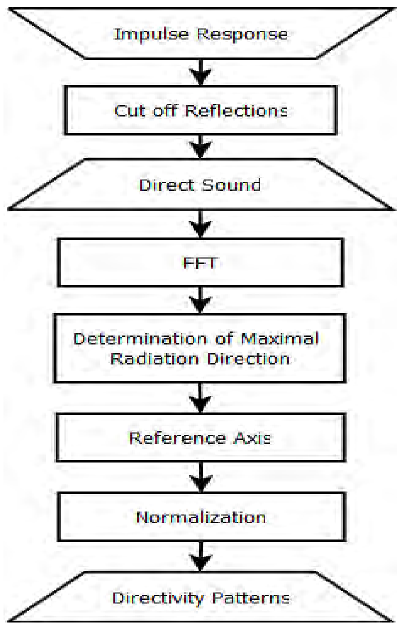


Fig. 3. Impulse response processing and determination of directivity radiation pattern

It should be kept in mind that processing of extracted parts of impulse responses, in order to obtain radiation directivity patterns, may also be performed in the time domain, as an alternative to processing in the frequency domain.

## IV. Results

For aforementioned configurations, the radiation directivities are obtained using the described procedures of measurement and processing in the frequency domain. Configuration of six independent elements from one half of dodecahedral loudspeaker array fed with same signal in phase, and the other six with opposite phase signal leads to the expected radiation patterns at lower frequencies, which tend to be close to bi-directional (Fig. 4(a)). By increasing frequency, the patterns begin to lose primary form, and in this case, at higher frequencies they get a flower shape (Fig. 4(b)).

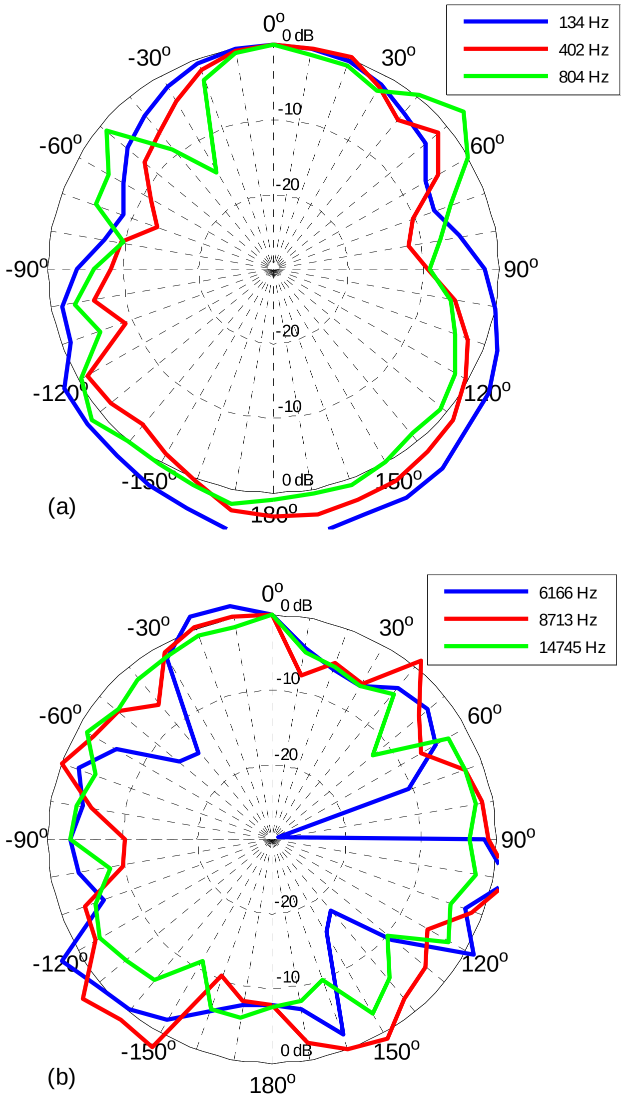


Fig. 4. Radiation directivity of dodecahedral loudspeaker array with six elements in phase and six elements in opposite phase at lower (a) and higher (b) frequencies

In the second configuration case, with two opposite elements fed with the same signal in phase, the obtained radiation characteristics are omni-directional at lower frequencies, while they get shape of narrowed figure-of-eight pattern at higher frequencies (Fig. 5.). For the last measurement configuration, where elements (loudspeakers) on opposite sides of dodecahedron are fed with opposite phase signals, the radiation patterns at both lower and higher frequencies have the expected bi-directional shape (figure-of-eight), see Fig. 6. From the presented results, it can be seen that the pattern is somewhat wider at lower frequencies (Fig. 6(a)), while it is somewhat narrower at higher frequencies (Fig. 6(b)).

It should be noted that for some directions, curves presenting radiation directivity come out of the range of 0 dB. This occurs because chosen reference axis is not the axis that has absolute maximum of radiation at all frequencies. Hence, regardless the criterion of referent axis choice, there is no uniform solution that yields the direction of absolute maximum at all frequencies. Due to that, the described disturbance in presenting the directivity radiation is inevitable. In all presented figures, the reference axis is positioned in the direction of 0°.

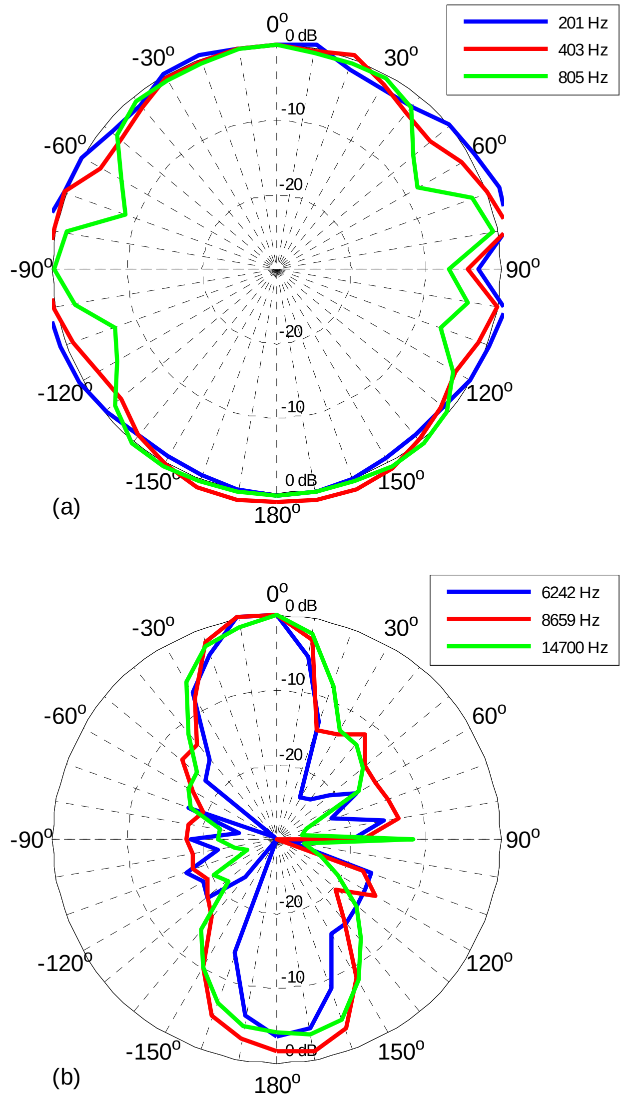


Fig. 5. Radiation directivity of dodecahedral loudspeaker array with two opposite elements in phase at lower (a) and higher (b) frequencies

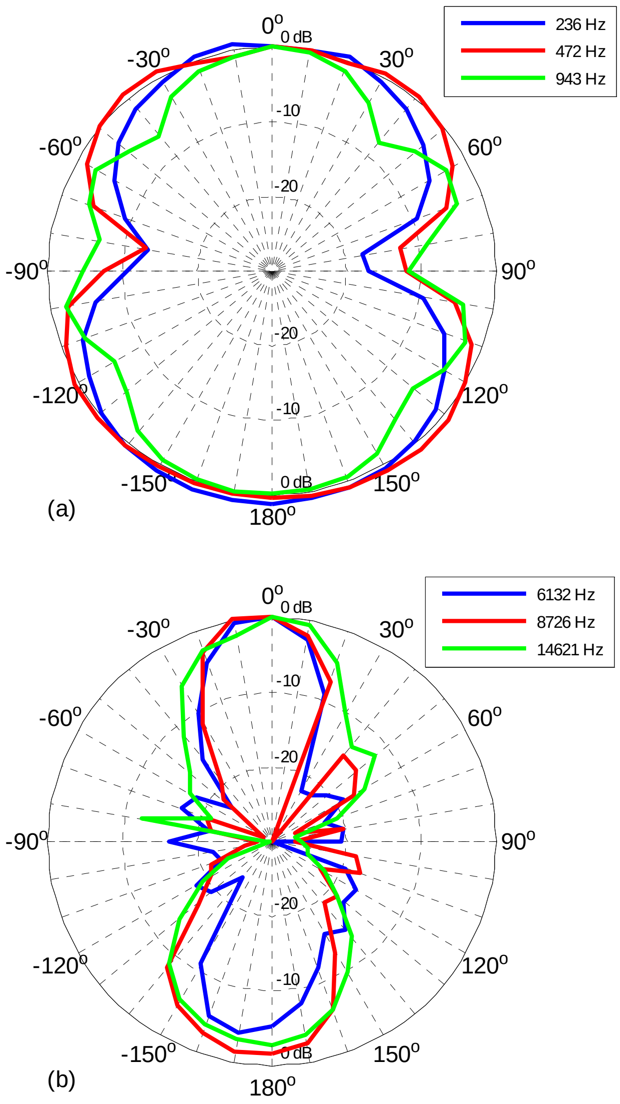


Fig. 6. Radiation directivity of dodecahedral loudspeaker array with two opposite elements, one in phase and one in opposite phase on lower (a) and higher (b) frequencies

## V. CONCLUSION

In this paper, radiation directivity of spherical sound source with independent elements in the form of dodecahedron is analyzed. The presented results and up to now experience show that using develop procedure of measurement, radiation directivity characteristics of sound source could be obtained in an adequate way. Measurement system along with the developed software support and measuring and processing procedures are well established and provides sufficient flexibility and control.

For the observed configuration cases, applying various combinations of excitations and disposition of elements (loudspeakers), some specific radiation directivity patterns can be achieved. Most of these patterns have the expected forms at lower frequencies - one omni-directional, and two approximately bi-directional patterns. At higher frequencies, their shape is changed and converges to the particular form.

The developed system for control of radiation directivity together with the system for measurement of this directivity will be involved in further research related to synthesis of some specific radiation directivity patterns similar to those of real sound sources.

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