RADIATION PATTERN MEASUREMENT WITH MATLAB IMPLEMENTATION

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Abstract

In the present paper a Matlab®-based program is developed for measuring the radiation pattern (polar response) of the loudspeaker using data acquisition system NI USB-6211, Matlab® Data Acquisition Toolbox and Matlab® Signal Processing Toolbox. A definition of the loudspeaker radiation pattern is presented along with block diagrams of the measurement setup and the program algorithm. A comparison between the theoretical and the experimental results has been made. Conclusions are drawn from the analysis of the study.

The proposed Matlab® program can be downloaded for free, from the link given at the end of the paper.

Keywords: Radiation pattern, Circular piston, Loudspeaker, Near field, Far field, Measurements, Matlab®.

INTRODUCTION

Manufacturing of large number of directed and hyper directed transducers has become possible because of the multiple studies of their radiation patterns. Those studies have undoubtedly improved and facilitated the use of the above-mentioned transducers in a great number of areas such as medicine, archeology, architectural acoustic, hydro acoustic, etc. [1, 2, 3].

There are various software products [4] and specialized measuring equipment [5] that can be used when examining the transducers' radiation pattern.

In the current paper authors' Matlab®-based program is used for measurement of radiation pattern with Data Acquisition Toolbox [6] and Signal Processing Toolbox [7] implementation.

Block diagrams of the experimental setup and the program algorithm are presented.

Finally, a comparison and analysis between the theory and the experimental data has been made.

THEORETICAL BACKGROUND

It is well known that the sound pressure produced by a circular piston is [8]:

$$p_\theta = \frac{\rho_s c_0 k v_m}{2\pi r} e^{j\omega t} \int_0^a x dx \int_0^{2\pi} e^{-jk(r+x\sin\theta\cos\alpha)} d\alpha. \tag{1}$$

where: c_0 is a speed of sound;

$k = 2\pi / \lambda$ – wave number;

v_m – particles velocity;

ρ_s – density of the environment;

λ – wave length;

r – distance between the piston and the microphone.

After integrating by α, Eq. (1) becomes [8, 9]:

$$p_\theta = \frac{\rho_s c_0 k v_m}{r} e^{-jkr} \int_0^a J_0(kx\sin\theta) x dx, \tag{2}$$

where $J_0(kx\sin\theta)$ is Bessel function of the zero kind of the argument $(kx\sin\theta)$, and after integrating by x, one obtains [8, 9]:

$$p_\theta = \frac{\rho_s c_0 k v_m a^2}{r} e^{-jkr} \frac{J_1(ka\sin\theta)}{ka\sin\theta}, \tag{3}$$

where $J_1(ka\sin\theta)$ is Bessel function of first kind of the argument $(ka\sin\theta)$.

The radiation pattern $G(\theta)$ is derived from the interrelation [10]:

$$G(\theta) = \frac{p_\theta}{p_0}, \tag{4}$$

where: p_0 is the sound pressure amplitude at the transducer's acoustic axis;

p_θ – the sound pressure amplitude at angle θ.

To calculate and visually represent a circular piston's radiation pattern it is necessary to determine the sound pressure level for $\theta = 0$. Due to the zero value of the θ angle:

$$\frac{J_1(ka\sin 0)}{ka\sin 0} = \frac{1}{2}, \tag{5}$$

and for the sound pressure level in that direction the following is valid:

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$$p_0 = \frac{\rho_m c_0 k v_m a^2}{r} e^{-jkr} \frac{1}{2}. \tag{6}$$

If one substitutes (6) and (2) in (4) the radiation pattern of a circular piston in the far field will be:

$$G(\theta) = 2 \frac{J_1(ka\sin\theta)}{ka\sin\theta}. \tag{7}$$

EXPERIMENTAL SETUP

At present the measurements are performed with, so called data acquisition system (DAQ) [11], which provides automatization of the measurement process and easy post-processing of the obtained data.

On Fig. 1 the block diagram of the experimental setup for measuring the radiation pattern of a loudspeaker is shown: DAQ-system NI USB-6211 [12], a laptop, a sound-level meter Robotron Präzisions with microphone MK202 and authors' Matlab®-based program. Different devices or transducers (loudspeakers, hydrophones, etc.) can be plugged in the DAQ-system outputs.
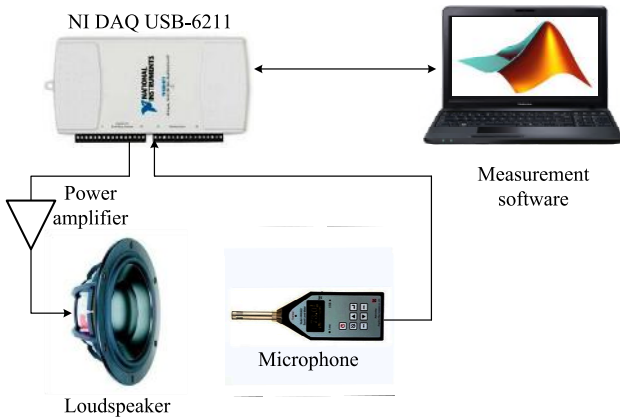

Fig. 1. Experimental setup block diagram.

On Fig. 2 a block diagram of the program algorithm is presented. In the program a time selection method is used [13] in which the received signal is strobe.

The program starts with adjustment of the measurement settings:

```
% measurement settings
fsout = 250000;
fsin = 250000;
f0 = 1000;
T = 0.5;
inrange = [-10 10];
calout = 1;
calin = 1;
```

After that the analog output and analog input must be prepared:

```
% preparation of the analog output
ao = analogoutput('nidaq', 'Dev1');
addchannel(ao, 0);
set(ao, 'SampleRate', fsout)
set(ao, 'TriggerType', 'Immediate')
set(ao, 'ExternalTriggerDriveLine', 'PFI4')
```

```
% preparation of the analog input
ai = analoginput('nidaq', 'Dev1');
addchannel(ai, 0);
set(ai, 'SampleRate', fsin)
set(ai, 'InputType', 'Differential')
set(ai.Channel(1), 'InputRange', inrange)
set(ai, 'TriggerType', 'HwDigital')
set(ai, 'HwDigitalTriggerSource', 'PFI3')
set(ai, 'TriggerCondition', 'PositiveEdge')
set(ai, 'SamplesPerTrigger', round(T*fsin))
```
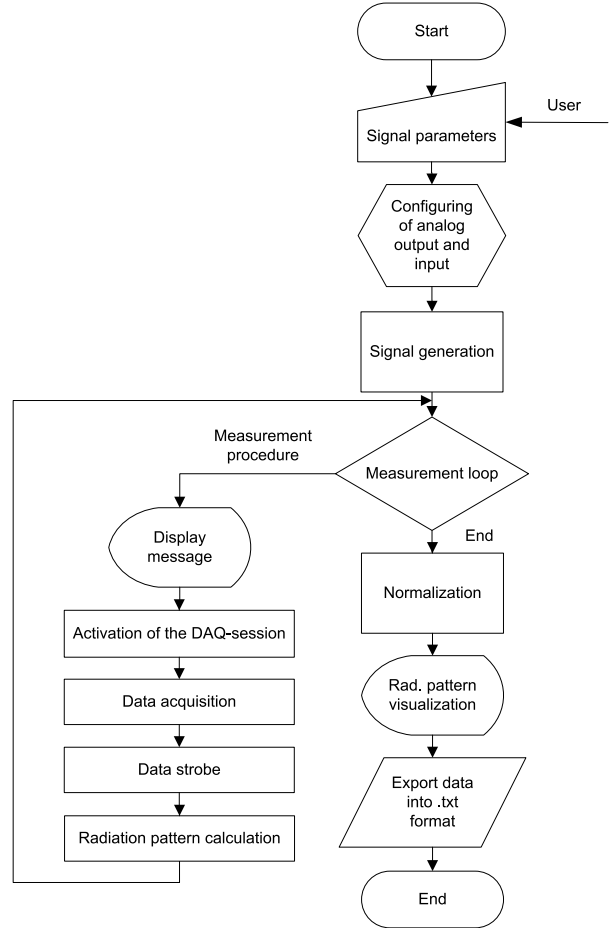

Fig. 2. Program algorithm.

The generation of the test sinusoidal signal is given by:

```
% preparation of the time vector
xlen = round(T*fsout);
t = (0:xlen-1)/fsout;

% generation of the signal
outdata = sin(2*pi*f0*t)'*calout;
```

The following code is the measurement procedure:

```
% measurement procedure
for c = 1:thetaveclen

    % display message
    disp(['Rotate to ' num2str(Thetavec(c)) ' deg
and press any key'])
    pause

    % activate the DAQ session
    putsample(ao, 0)
    putdata(ao, outdata)
    start([ai ao])

    % get data
    wait(ai, 1.1*T+0.5)
    indata = getdata(ai);
```

```
    % stop the DAQ session
    stop([ai ao])
    flushdata(ai)

    % strobe the data
    indata = indata(20000:30000)*calin;

    % calculate the radiation pattern
    [RP, ~] = freqrespmeasure(outdata, indata);

    % save the data into radiation pattern vector
    RPvec(1, c) = RP;

end
```

The `freqrespmeasure` function is authors' file-function for measurement of the frequency response of two- or four-port circuit using single-tone sine waves with increasing frequency and DFT [14]. The function is used, since the radiation pattern could be represented as a frequency response of the loudspeaker at different directions, but at one and the same frequency.

When one obtains the radiation pattern vector, normalization must be applied:

```
% normalize
RPvec = RPvec/max(RPvec);
```

The measured radiation pattern is visualized at the final stage of the program:

```
% plot the radiation pattern
figure(1)
polar(Thetavec,  RPvec, 'r')
grid on
set(gca, 'FontName', 'Times New Roman',
'FontSize', 14)
title(['Radiation pattern of loudspeaker at '
num2str(f0) ' Hz']);
view(-90, 90)
```

In addition the obtained experimental data can be saved as .txt file for further processing:

```
% save the data in .txt file
D = [Thetavec' RPvec'];
dlmwrite('dataLSP.txt', D, 'delimiter', ' ',
'newline', 'pc');
```

On Fig. 3 the output .txt file is presented. The angle (in radians) is in the first column while the second column contains the normalized sound pressure level.
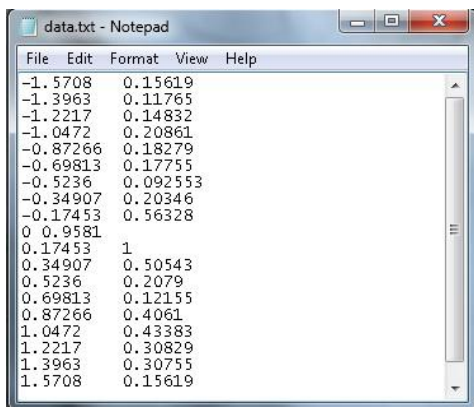

Fig. 3. Experimental data text file.

EXPERIMENTAL RESULTS

The program presented above has been used for multiple measurements of loudspeakers' radiation patterns, including one of a circular piston. The measurements took place in an anechoic chamber at Technical University – Varna.

On Fig. 4÷9 the experimental results from radiation pattern measurement are shown. The objects of the study are two identical circular loudspeakers - JBL (*loudspeaker 1* and *loudspeaker 2*) with nominal diameters of $0.13\,m$. The frequency was selected so that $k \cdot a = 7.02$. At the figures solid red line represents a theoretical radiation pattern calculated by Eq. (9), and the solid black line with stars – one obtained by a measurement.
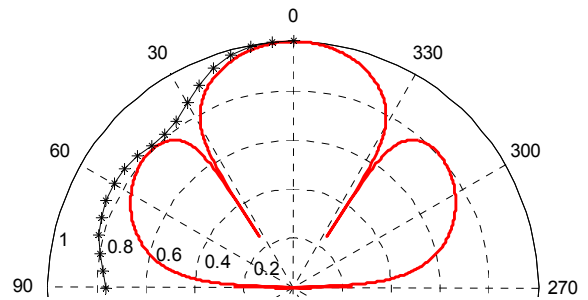

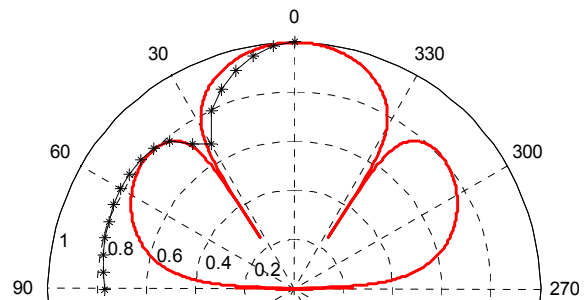*Fig. 4. Radiation pattern at $0.15\,m$ from loudspeaker 1.*

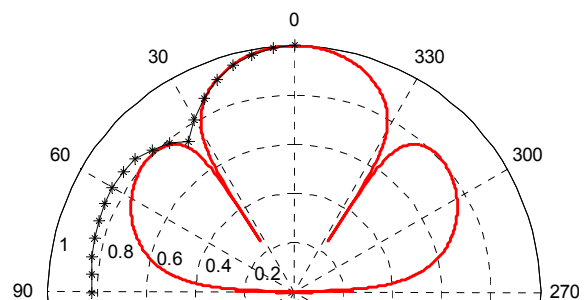*Fig.5. Radiation pattern at $0.60\,m$ from loudspeaker 1.*

Fig. 6. Radiation pattern at $2.40\,m$ from loudspeaker 1.
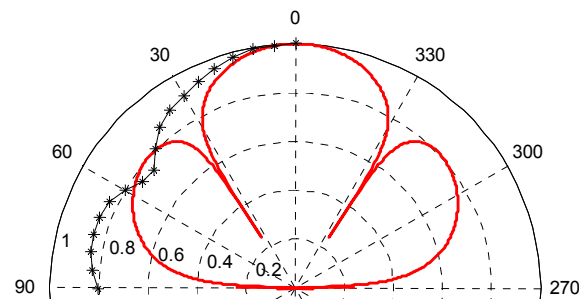

Fig. 7. Radiation pattern at $0.15\,m$ from loudspeaker 2.
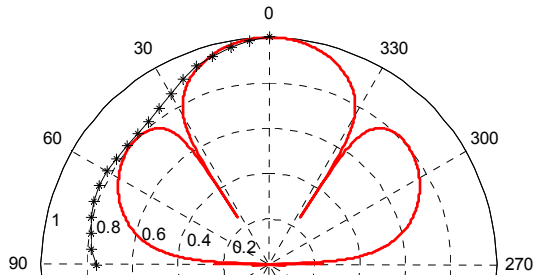
Fig. 8. Radiation pattern at $0.60\,m$ from loudspeaker 2.
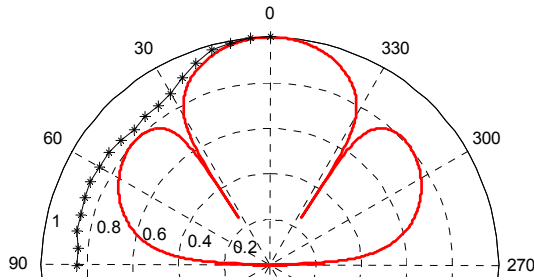

Fig . 9. Radiation pattern at $2.40\,m$ from loudspeaker 2.

CONCLUSION

From Fig. 4÷9 one can deduce that the radiation pattern measurement program gives accurate results. A more detailed analysis of the incoherence between the theoretical radiation pattern and the one obtained from the experiments in the near field can be found in [15].

The presented program codes (for the radiation pattern and the strobe) are accessible at:
http://www.mathworks.com/matlabcentral/fileexchange/46233-measurement-of-loudspeaker-radiation-pattern-with-matlab-implementation.

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