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# DIRECTIONAL PROPERTIES OF THE LOUDSPEAKER SYSTEMS WITH ANALOG AND DIGITAL CROSSOVER NETWORKS

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Directional properties of loudspeaker systems with analog and digital crossover networks have been investigated. The study has been performed for a three-way loudspeaker system subjectively classified as of average quality. The digital crossover networks have been designed in such manner that the cut-off frequencies of filters (1000 Hz and 5000 Hz) corresponded to those of the analog networks and the slopes of the amplitude characteristics were 12 and 18 dB/oct. The set of impulse responses for different angles in the whole sphere around the loudspeaker system were measured and then, applying a convolution with the excitation signals of the "tone burst" type, for some specific frequencies from the cut-off region of crossover networks, the directional characteristics have been calculated for the steady and transient states. The quantitative analyses of results, based on the values of directional coefficient, show significant differences between the characteristics in steady and transient states, as well as for the analog and digital systems.

**Keywords:** analog crossover network, digital crossover network, transient states, directivity.

## 1. Introduction

The problem of directional properties of electroacoustic transducers acquire a special significance in the case of loudspeaker systems used in the process of stereophonic transmission or in the process of sound reinforcement. The essential condition of proper reception of acoustical signal is the independence of spatial aural sensation, as far as possible, from the location of a listener in a room. The area size where the spatial aural sensation is correct is dependent – besides acoustical properties of a room – on the location of loudspeaker systems in the room and their directional properties [1]. The investigations carried out on loudspeaker systems revealed some essential differences in the course of the frequency response on the system axis and outside it, particularly for the frequencies from the cut-off region of crossover networks. The subjective evaluation of the loudspeaker system may, therefore, depends on the spatial conditions in which it has been performed. Directivity of sound source plays than an important role in the process of sound reinforcement and the knowledge of directional properties of sound source has an essential importance for an appropriate modeling of physical phenomena which accompany this process [2].

The quality of the sounds reproduced by the loudspeaker systems depends significantly on the transmission of transients. This becomes all the more obvious when one realizes that the real sounds (e.g. speech, music, environmental sounds) are signals of purely transient nature. The distortions occuring in transients depend on both the width of transmission range and irregularity of frequency characteristic. The mentioned above phenomena influence in a great degree the directivity of radiation of loudspeaker systems. In the investigations concerning the directional properties of sound sources the sinus or noise type signals are usually used – in this cases this properties remain constant. The investigations carried out, among others, by present author showed, that directional properties of loudspeaker systems in steady and transient states differ significantly [4, 5].

The application of the DSP technique in construction of the crossover networks of the loudspeaker systems enables to create their transmission properties, and hence also directional characteristics, to a much greater degree than in the analog systems [6]. Changes in the cut-off frequency and the slope of the amplitude characteristic of the crossover filters can bring about significant differences in the directional characteristics of the loudspeaker systems and thus differences in the resulting effect of sound reinforcement in a room. The problem is of particular significance for the multi loudspeaker systems, the so-called loudspeaker matrices, whose successful operation depends on the geometrical relations in the room responsible for the signal time delays and changes in the directional characteristics. The main demand as to the directional characteristics of a loudspeaker system is to ensure the uniform sound propagation into the frontal hemisphere. However, small sound propagation into the back hemisphere can bring some improvement by eliminating significant apparent sources behind or at the sides of the loudspeaker system. The efficiency of sound propagation into the frontal hemisphere is ensured by the set of digital filters of the class FIR [7, 8] ensuring linear phase distortions, which cannot be ensured either by active or passive Butterworth or Czebyszew filters [9, 10].

An additional element often met in the crossovers of this type is the supplementary inverse correction filter, operating according to the formulae:

$$h_{ls}(t)^* h_{cif}(t) = d(t), \tag{1}$$

where $h_{ls}(t)$ – impulse response of the loudspeaker system, $h_{cif}(t)$ – impulse response of the correction inverse filter, $d(t)$ – Kronecker delta, $^*$ – convolution operation.

Determination of the impulse response parameters is subject to some restrictions [11]. First of all the amplification coefficient must be limited in the conditions in which the loudspeaker system is not effective [relatively little effective]. It usually exists in the cases when radiating sound in the lowest frequency range as well as in these regions of frequency in which the effectiveness of emission is by 15–20 dB lower than the mean value for the whole range. The too high amplification coefficient means that the system is driven in the range of nonlinear signal processing, which is obviously reflected in the subjective assessment of the sound signal perceived.

The main aim of the investigations presented in this paper was to show in which manner the replacement of analog to digital crossover network influences directional properties of loudspeaker system.

## 2. Experimental investigations

### *2.1. Object of study*

The study was performed for the three-way loudspeaker system GRUNDIG, subjectively classified as of average quality class. Figure 1 presents the scheme and parameters of the analog crossover network of the system.

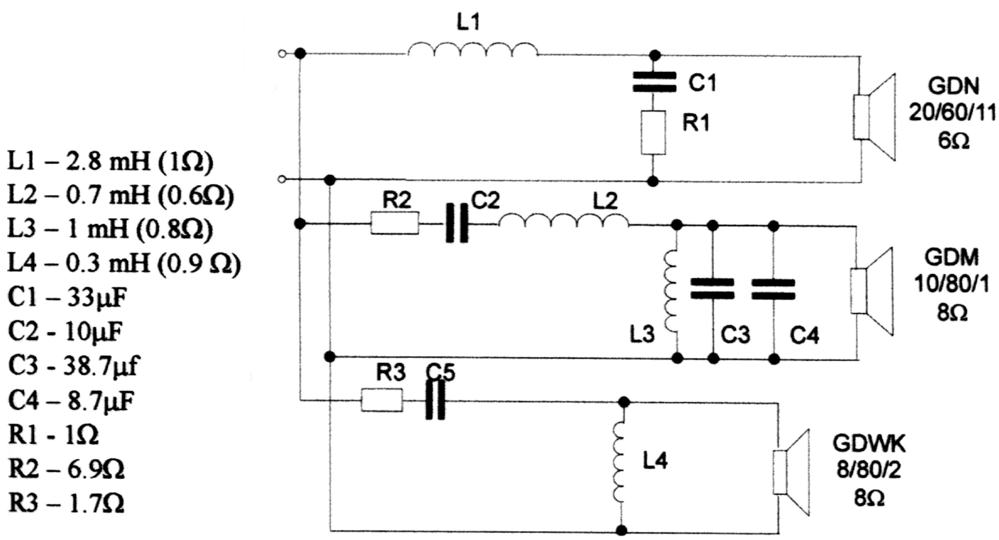


Fig. 1. Construction scheme and parameters of the analog crossover network.

In Fig. 2 the frequency characteristics of the analog filters measured on loading with loudspeakers are presented.

The impulse response and the frequency characteristic of the analog system described above are presented in Fig. 3.

The cut-off frequencies of the filters were 1000 Hz and 5000 Hz. On the basis of the above data two digital filters characterised by the same cut-off frequencies and the slopes of transmission characteristics of 12 and 18 dB/oct have been designed, Fig. 4.

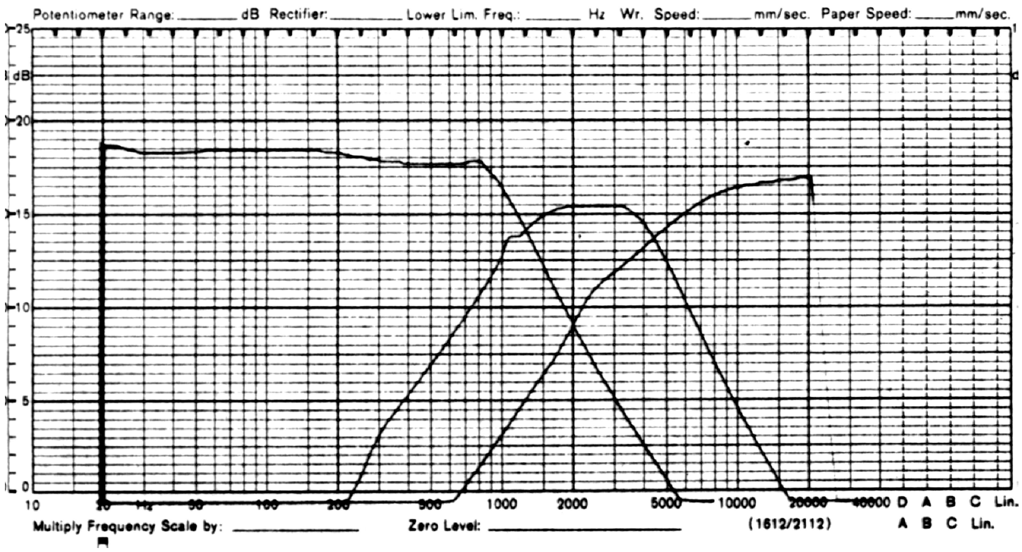


Fig. 2. Frequency characteristics of the analog crossover filters.

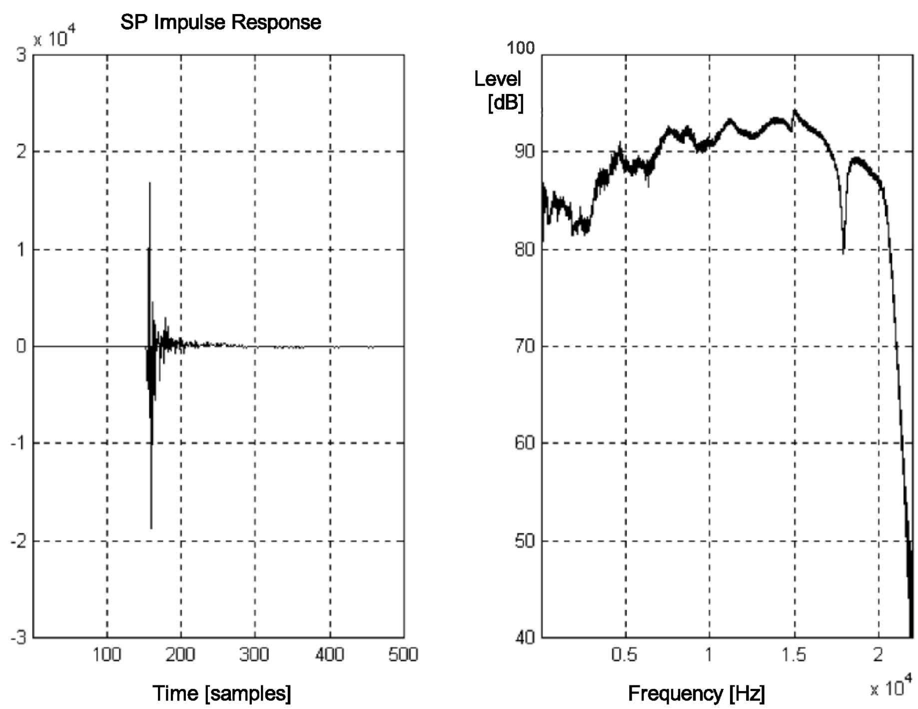


Fig. 3. Impulse response and frequency characteristic of the analog loudspeaker system.

It should be emphasised that in both digital crossover networks the slopes of 12 or 18 dB/oct refer to the high-pass and low-pass filters. The band-pass filter is a resul-

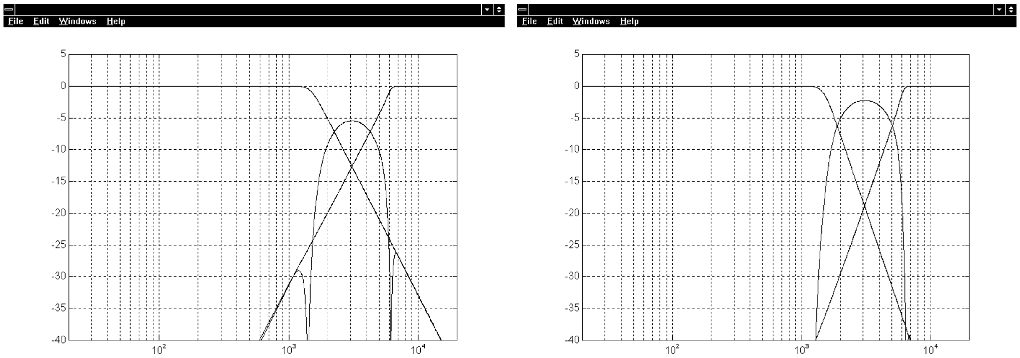


Fig. 4. Frequency characteristics of the digital filters of the transmission characteristic slope of 12 dB/oct and 18 dB/oct.

tant one whose frequency characteristic should ensure that the characteristic of entire crossover network would be flat so that the impulse response would be close to the Kronecker delta $d(t)$. The compensated impulse responses and frequency characteristics of digital loudspeaker systems are demonstrated in Fig. 5.

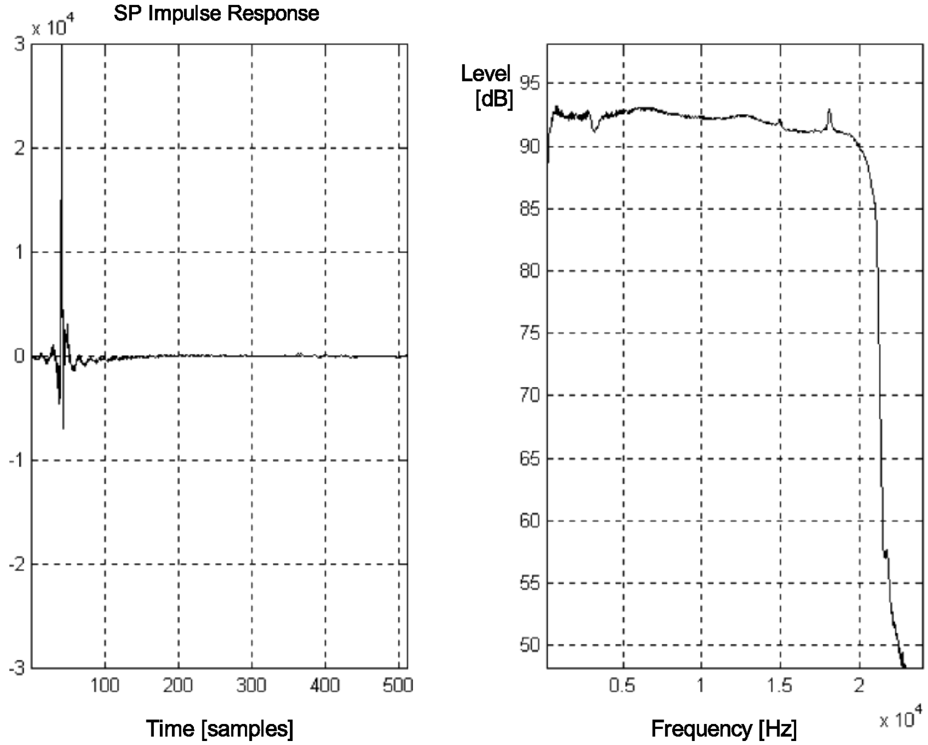


Fig. 5. Compensated impulse response and frequency characteristic of digital loudspeaker system.

### 2.2. *The methodology of measurements and calculations*

Figure 6 presents a block diagram of the measurement setup for determining the impulse responses of loudspeaker systems at the measuring points within the full sphere around the system.

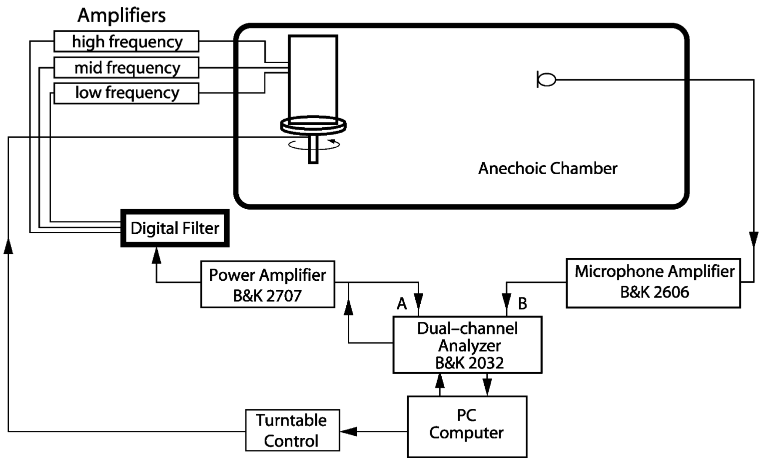


Fig. 6. Block diagram of the measurement setup for determining the impulse response of loudspeaker system.

The method applied is based on the use of noise signal. The main element of the setup is a two-channel analyser B&K 2032, which generates the excitation signal and records the signals at the input and output of the loudspeaker system. At the next stage both signals are subjected to FFT and then divided to get transmittance $H(\omega)$. Finally, as a result of the inverse FFT we receive the impulse response of the loudspeaker system. It is known that the impulse response fully characterises the properties of a given system. As mentioned earlier, very important for determination of the directional properties of a loudspeaker system is the knowledge of directional characteristics not only for the steady state but also for the transient states (especially the initial transient). Particularly suitable for the study of this kind is the tone burst type signal – a tonal pulse of rectangular envelope. The procedure described is based on a program, which – thanks to the convolution of the pulse response and the tone burst signal – enables determination of the pulse response of a loudspeaker system for any frequency at both steady and transient states. Figure 7 presents the exemplary course of the electrical excitation signal and the acoustical response of the loudspeaker system (in this case frequency was 1 kHz and duration 40 ms – the amplitudes of excitation and response were equalized in arbitrary units).

As follows from Fig. 7, in the response there are clearly distinguished fragments corresponding to the initial transient, steady state and final transient. Thus, using an appropriate computer program it is possible to obtain the directional characteristics for an arbitrary fragment of the response signal. The calculations were conducted for first

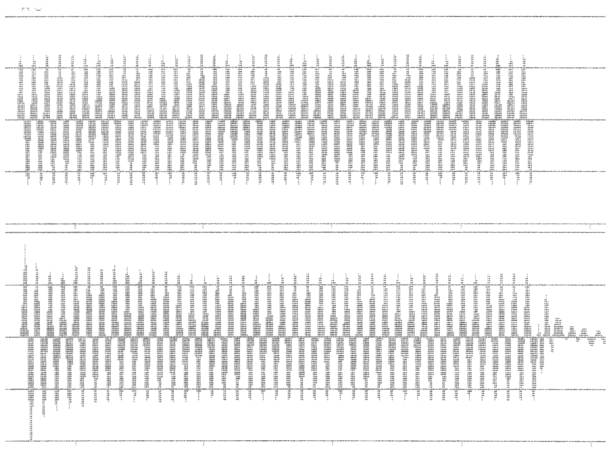

Fig. 7. The course of the exemplary "tone burst" excitation signal and the response of the loudspeaker system.

two ms of initial and final transients. As a quantitative measure of directional properties of the loudspeaker systems under investigation, the directivity coefficient was adopted.

The directivity coefficient is described by the following formulae:

$$Q = \frac{p_0^2}{(p^2)_{\text{av}}}, \tag{2}$$

where $p_0^2$ – the square value of acoustic pressure in a given point on the main axis of a source, $\left(p^2\right)_{\text{av}}$ – the mean square of acoustic pressure on the surface of a sphere, in centre of which sound source is located.

## 3. Results

The results of calculations of radiation parameters of loudspeaker systems under investigation are collected in Tables 1–4.

**Table 1.** Radiation parameters for $f = 750$ Hz.

| | hor | ver | Q1 | Q2 | Pa1 [W] | Pa2 [W] |
|---|---|---|---|---|---|---|
| La12-075-i | 0° | 330° | 10.8 | 6.5 | 2.5882 | 1.8130 |
| La12-075-ss | 0° | 30° | 12.8 | 9.4 | 4.9777 | 3.7145 |
| La12-075-f | 345° | 30° | 16.9 | 12.4 | 1.7133 | 1.2860 |
| Ld12-075-i | 0° | 15° | 5.9 | 3.5 | 0.8242 | 0.6047 |
| Ld12-075-ss | 345° | 15° | 9.7 | 5.6 | 1.2855 | 0.9880 |
| Ld12-075-f | 345° | 15° | 17.1 | 11.6 | 0.1468 | 0.1166 |
| Ld18-075-i | 0° | 15° | 6.1 | 3.5 | 0.7830 | 0.5782 |
| Ld18-075-ss | 345° | 15° | 9.7 | 5.2 | 0.2195 | 0.9425 |
| Ld18-075-f | 0° | 30° | 15.6 | 9.6 | 0.1464 | 0.1135 |

**Table 2.** Radiation parameters for $f = 1070$ Hz.

| | hor | ver | Q1 | Q2 | Pa1 [W] | Pa2 [W] |
|---|---|---|---|---|---|---|
| La12-107-i | 0° | 330° | 23.1 | 14.1 | 6.0505 | 4.6625 |
| La12-107-ss | 0° | 30° | 71.6 | 51.3 | 6.0830 | 4.9843 |
| La12-107-f | 0° | 15° | 17.4 | 12.9 | 1.8295 | 1.3621 |
| Ld12-107-i | 0° | 0° | 14.9 | 8.8 | 1.4122 | 1.0447 |
| Ld12-107-ss | 0° | 0° | 15.2 | 8.2 | 0.6952 | 0.5061 |
| Ld12-107-f | 0° | 30° | 17.4 | 12.3 | 0.3909 | 0.3077 |
| Ld18-107-i | 0° | 0° | 13.9 | 8.3 | 0.6809 | 0.4894 |
| Ld18-107-ss | 0° | 0° | 16.0 | 8.4 | 0.3863 | 0.2833 |
| Ld18-107-f | 0° | 30° | 12.8 | 10.1 | 0.2569 | 0.1938 |

**Table 3.** Radiation parameters for $f = 4770$ Hz.

| | hor | ver | Q1 | Q2 | Pa1 [W] | Pa2 [W] |
|---|---|---|---|---|---|---|
| La12-477-i | 330° | 15° | 50.79 | 23.95 | 0.3411 | 0.2914 |
| La12-477-ss | 0° | 330° | 46.03 | 16.70 | 0.8508 | 0.6883 |
| La12-477-f | 330° | 0° | 28.36 | 11.95 | 0.2652 | 0.1927 |
| Ld12-477-i | 15° | 30° | 36.88 | 6.04 | 0.7783 | 0.6778 |
| Ld12-477-ss | 0° | 30° | 29.30 | 11.32 | 1.3918 | 1.1474 |
| Ld12-477-f | 30° | 30° | 16.46 | 7.32 | 0.2239 | 0.1610 |
| Ld18-477-i | 0° | 30° | 28.22 | 6.83 | 0.7824 | 0.6456 |
| Ld18-477-ss | 330° | 0° | 28.99 | 13.12 | 0.9879 | 0.7804 |
| Ld18-477-f | 30° | 0° | 16.01 | 9.46 | 0.1823 | 0.1250 |

**Table 4.** Radiation parameters for $f = 5500$ Hz.

| | hor | ver | Q1 | Q2 | Pa1 [W] | Pa2 [W] |
|---|---|---|---|---|---|---|
| La12-550-i | 345° | 330° | 51.8 | 6.9 | 3.8250 | 3.4203 |
| La12-550-ss | 345° | 30° | 42.6 | 10.4 | 1.8359 | 1.6350 |
| La12-550-f | 0° | 315° | 35.4 | 14.7 | 1.0968 | 0.8918 |
| Ld12-550-i | 15° | 30° | 36.9 | 7.3 | 1.2913 | 1.1437 |
| Ld12-550-ss | 345° | 15° | 9.7 | 5.2 | 1.2195 | 0.9425 |
| Ld12-550-f | 330° | 345° | 15.6 | 8.6 | 0.3356 | 0.2554 |
| Ld18-550-i | 15° | 45° | 45.4 | 10.0 | 1.1527 | 1.0031 |
| Ld18-550-ss | 15° | 30° | 47.0 | 18.7 | 1.7133 | 1.5111 |
| Ld18-550-f | 0° | 315° | 51.2 | 26.5 | 0.3857 | 0.3193 |

Legend:
La12 – analog system 12 dB/oct; Ld12 – digital system 12 dB/oct; Ld18 digital system 18 dB/oct;
$075 - f = 750$ Hz; $107 - f = 1070$ Hz; $477 - f = 4770$ Hz; $550 - f = 5500$ Hz;
i – initial transient; ss – steady state; f – final transient;
hor, ver – angle between the geometric axis and the axis of maximum radiation of the system, clockwise direction in horizontal plane and up-direction in vertical plane;
Q1, Q2 – directivity coefficient for the whole sphere and frontal hemisphere, respectively;
Pa1, Pa2 – power radiated in the whole sphere and frontal hemisphere, respectively.

Exemplary directional characteristics determined for the steady and transient states (initial and final) for the loudspeaker system with analog and digital crossover networks (12 dB/oct) are presented in Fig. 8.

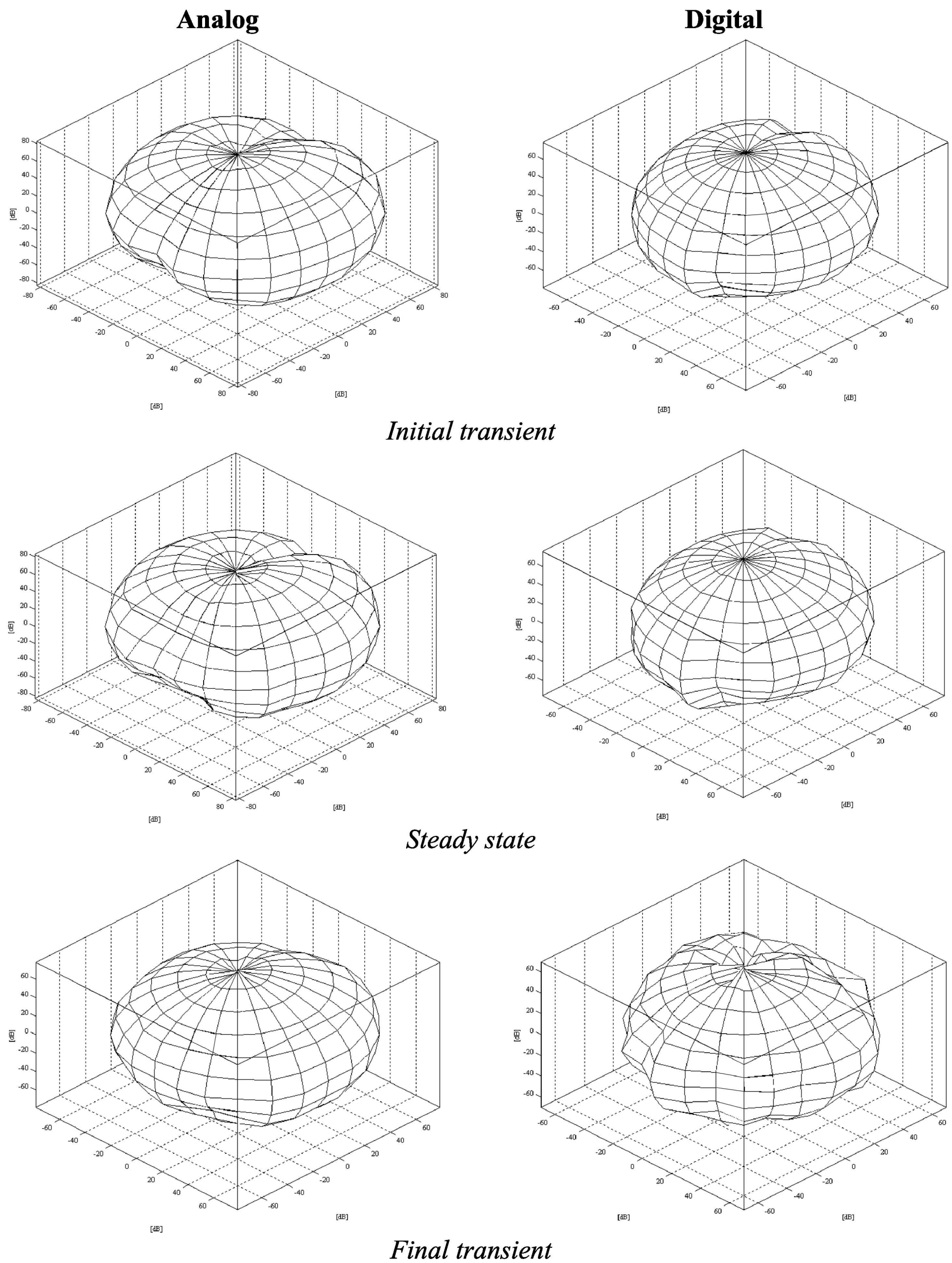


Fig. 8. Directional characteristics of loudspeaker system with analog and digital crossover networks (12 dB/oct) for the frequency 1070 Hz.

## 4. Discussion of results

The analysis of data contained in Tables allows for detailed comments of the results:

- only in some cases the axis of maximal radiation covers the geometric axis of the system (for $f = 1070$ Hz) while in the most cases the differences of 15–30° exist, especially in vertical plane,
- the values of directional coefficients indicate that the digital systems are closer to omnidirectional when comparing with analog systems,
- directional coefficients Q1 and Q2 differ significantly – the values Q2 are much lower that means the directional characteristics in frontal hemisphere are more uniform (result which could be excepted),
- power radiated by the systems in the initial transient and steady state depend on the frequency of excitation – for the local maximum ($f = 750$ Hz and $f = 4770$ Hz) power in the steady state exceeds power in transient but for local minimum ($f = 1070$ Hz and $f = 5500$ Hz) the relations are inverted,
- power radiated in the final transient is significantly lower,
- differences of directional properties between digital systems (12 dB/oct and 18 dB/oct) are much less intrinsic when comparing with analog systems.

## 5. Conclusions

The results obtained in the investigations reveal significant differences between the directional properties of loudspeaker systems with crossover networks of different types, evaluated for the steady and transient states. That should be taken into account when the process of sound reinforcement in room is realized. The differences do not favour one type of the crossover network over the other, but indicate that careful choice must be make to match the demands of specific acoustic conditions.

The systems with digital crossover networks are characterized with greater efficiency of emission in the frontal hemisphere, but it does not necessarily mean that they are better. The great advantage of these systems consists on the possibility in changing on a simple way the parameters of crossover network which would cause the modification of the frequency and/or directional characteristics. But in fact, the most important criterion of selection of suitable system should be connected with the subjective evaluation of perceived acoustical sensations.

## Acknowledgment

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