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Polar Measurements of Harmonic and Multitone Distortion of Direct Radiating and Horn Loaded Transducers

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ABSTRACT

While extensive literature is available on the topic of polar pattern measurements and predictions of loudspeakers fundamental SPL, only a single paper to our knowledge deals with the polar pattern of nonlinear distortions, in particular with harmonic distortion products of cone type loudspeakers. This paper contains the first results of a more thorough study intended as a complement to fill the gap both in measurement techniques and loudspeakers type. Relative and absolute harmonic distortion as well as relative and absolute multitone distortion indeed have been measured for cone, dome and horn loaded transducers.

1. INTRODUCTION

Harmonic distortion is an old and quite well understood measurement and although not meaningful alone to predict subjective preferences it’s useful in development to compare design options and in production for quality control. In [1] polar measurements of cone type loudspeakers have resulted in harmonic distortion products following the fundamental polar pattern at the frequency of the distortion product for frequencies below ka=1.

Multi Tone Nonlinear Distortion (MTND) on the other hand is a more recent measurement, with the stimulus which has a spectrum similar to typical musical program. In this case the distortion products created by both harmonic and intermodulation distortion that continuously fill the spectrum between stimulus signal lines, can be plotted in a continuous frequency dependent curve [2-3]. Perceptual models applied to multitone distortion measurements have scored quite well regarding subjective preferences prediction [4-5].

The scope of this paper is to present some preliminary data mainly as color map pictures of a huge collection of measurements performed on many different loudspeakers to establish correlations between loudspeaker type and distortion polar pattern.

2. METHODOLOGY

The measurements have been performed in a large room inside Lavoce Italiana R&D laboratory. The measurement system consists of a Klippel Distortion Analyzer 2 with TRF, LPM and POL/Robotics software modules, a professional power amplifier with low noise fans, an omnidirectional microphone with low noise, 139dB max SPL capability and 35kHz high frequency cutoff, a turntable, R&D Team “VACS” software for post-processing.

The TRF module relies on the log-sweep technique [6-8] to separate fundamental and harmonic distortion products impulse responses (IR). While the fundamental IR can be manually windowed by the user, harmonics IR are automatically windowed by the software with an adaptive window, which varies with the selected bandwidth and resolution. The minimum frequency of the sweep was chosen according to the minimum frequency where the DUT could withstand nominal power handling. The maximum frequency of the sweep was chosen as high as possible and just above the microphone cutoff to get enough extension in harmonic distortion products analysis. Sweep resolution was chosen as fine as possible in order to clearly separate harmonics IR in the tail of the fundamental IR which is quite slow in the decay because of the high reverberation time of the large room used. No averaging was used, to avoid time variant behavior of the speaker caused by voice coil heating in successive averages. The voltages applied were chosen in order to get enough distortion to noise ratio of the harmonic with the lower SPL and to get the same average fundamental SPL from speakers belonging to the same category.

The LPM module uses a multitone stimulus. The lower frequency signal line was chosen according to the minimum frequency where the DUT could withstand nominal power handling, and high enough in order to get a stimulus duration which was sufficiently short to reduce as much as possible the effect of the nearest reflection from the wall to enter the acquisition time window of the measurement. This has led, for the Full Range speakers, to raise the minimum frequency to 400Hz. The maximum frequency of the signal lines was chosen as high as possible, and is limited by the hardware at 18kHz. Relative resolution was chosen after some tests at $1/12^{th}$ octave as a good compromise between smoothness of the MTND curve and the spacing between bins to avoid distortion products masking by signal lines [9-10]. The resulting crest factor value is 9.5dB for Dome Tweeters and 11.5dB for Full Ranges. No averaging was used, to avoid time variant behavior of the speaker caused by voice coil heating in successive averages, and to reduce the total signal time duration in order to minimize wall reflection effects. The voltages applied were chosen in order to get enough distortion to noise ratio of the distortion products and to get the same average fundamental SPL from speakers belonging to the same category.

Earlier tests have been performed to assess the harmonic and MTND polar pattern dependence on level, finding at least in the SPL range tested no significant dependence, as already found in [1].

POL/Robotics turntable control software provided by Klippel [11] for integration of polar measurements in LPM and TRF modules was set at 5 Degree angular resolution on an angular range from 0 to 90 Degree with data mirroring done in post processing.

Measurements distance was chosen in order to be at least for Fundamental and Harmonics measurements in the far field of the DUT, and as low as possible to increase the SNR given the trade-offs we had to deal with because of the “echoic” character of the measurement environment. For MTND given the fact that the acquisition time window is related only to resolution and lowest frequency of the multitone signal, the measurements were performed also at closer distances in order to reduce wall reflection effects.

Noise floor average value for all the measurements in the 100Hz-2.5kHz range was 35dB SPL while in the 2.5kHz-40kHz range was 20dB SPL.

The total number and type of DUT measured for each category are:

-No.5 Full Range Cone type loudspeakers with both types of soft and metal cone material, mounted in a closed box with front panel of about the same width of cone diameter;

-No.7 Dome Tweeter loudspeakers with both types of soft and metal dome material mounted in free air;

-No.6 Horn Loaded High Frequency loudspeakers with both types of soft and metal dome material. Three of them are the same Dome Tweeter of the previous category, with their phase plug added. All of them were mounted on a constant directivity horn with 1.5kHz low frequency cutoff and 90x60 Degree nominal coverage, measured along the 60 Degree plane.

For each loudspeakers model two samples have been measured and then only one has been chosen as the reference for that model. Only six loudspeaker data set are presented in the following pages (see Figure 1 for details), significantly representing the different behavior we have encountered for each category of speakers.

Type	TRF (on-axis)				LPM (on-axis)			
	Average SPL between	Voltage	Stimulus	Meas. Dist.	p mean level	Voltage	Stimulus	Meas. Dist.
	(Fmin-Fmax): [dB]	[V]	(Fmin-Fmax):[Hz]	[cm]	(Fmin-Fmax):[Hz]	[V]	(Fmin-Fmax):[Hz]	[cm]
76mm Full Range Soft Cone	(400-10k Hz): 90	2.6	100-40k	50	79	5.3	400-18k	12.5
76mm Full Range Metal Cone	(400-10k Hz): 90	6.2	100-40k	50	79	14	400-18k	12.5
25mm Soft Dome Tweeter	(2.5k-20k Hz): 95	3	2500-40k	25	88	8	2,5k- 18k	25
25mm Metal Dome Tweeter	(2.5k-20k Hz): 95	9	2500-40k	25	88	15.2	2,5k- 18k	25
CD_Horn_25mm Soft Dome Tweeter	(2.5k-20k Hz): 100	1.45	2500-40k	50	99	8	2,5k- 18k	50
CD_Horn_25mm Metal Dome Tweeter	(2.5k-20k Hz): 100	3	2500-40k	50	99	16	2,5k- 18k	50

Figure 1:DUT types and measurement conditions

3. MEASUREMENTS ANALYSIS AND DISCUSSION

During the study, both relative and absolute values of distortions were investigated. In order to better distinguish distortion products from noise floor, only absolute values are presented here.

The measurements are presented always in the same order of Fundamental, 2nd harmonic, 3rd harmonic and Multi Tone Nonlinear Distortion.

Microphone sensitivities have been adjusted in order to read SPL referred to 1m distance for all the different measurement distances. Please note that while the fundamental has the plotted maximum frequency set at 40kHz, harmonics and MTND frequency range stops at 20kHz. The minimum frequency is set according to stimulus ranges in Figure 1. The SPL range has been set with the minimum value corresponding to the average noise floor level in the 2.5-40kHz frequency range, while the maximum value is set for fundamental and MTND as the maximum value in each data set, while for harmonics the maximum value among data sets of both harmonics has been chosen in order to compare more easily also the magnitude of the two different orders of harmonic distortion.

Instead of statistically analyze for selected frequencies the huge amount of data collected, color maps will be presented with Frequency on abscissa axis, Axial Angle on ordinate and SPL in color scale in order to visually establish correlation between the fundamental polar pattern and harmonic/MTND distortion polar pattern.

As can be verified through visual inspection and comparing the plots of fundamental and harmonic distortion with frequency scaling in mind, the harmonic distortion seems to roughly follow the fundamental polar pattern for all type of loudspeakers at frequencies where the distortion is produced, as already found in [1]. Looking at relative harmonic distortion plots, not presented here, due to "relative to the fundamental nature", it can be seen that they have maxima often corresponding to fundamental minima which are related to radiation lobing or cone/dome breakups that involve anti-phase and quadrature components. The relative MTND has a weird behavior too, since below a certain transition frequency the maxima are off axis, and above that transition frequency the maxima follow the fundamental polar pattern with maxima mainly along the axis. This is due to the greater SPL loss in high frequencies than in low-middle frequencies when measuring at increasing angles off-axis and the average value taken as reference to calculate the relative value.

Commenting on some peculiarities encountered in each speaker category, the metal cone Full Range suffers from a strong resonance visible as a peak at about 12 and 18 kHz in the 2nd harmonic and at about 12 kHz in the 3rd harmonic along all the measuring angle, a vertical band in the plot of both harmonics.

For the horn loaded dome tweeters, the constant directivity of the fundamental reflects in an almost constant directivity of MTND for both models. As verified also for some poorly designed compression drivers whose data are not included in this paper, where the phase plug doesn’t provide a coherent plane wavefront at the driver mouth, the harmonic distortion and MTND data strongly reflects these anomalies: this can be seen also comparing Figure 6 versus Figure 7, where the single slot phase plug mounted on the soft dome forward radiating driver is clearly a better performer for what concerns the smoothness and regularity of directivity of distortion products versus the two slot phase plug design mounted on the metal dome forward radiating driver when coupled to the same CD horn.

The polar pattern of the fundamental measured in SPL for each direct radiating speaker has also been compared to the one computed by Klippel SCN software from laser scanning vibrometer data with good agreement, confirming that the chosen measurement setup doesn't affect perceivably the far field directivity by means of stand reflections or panel diffraction for Full Ranges.

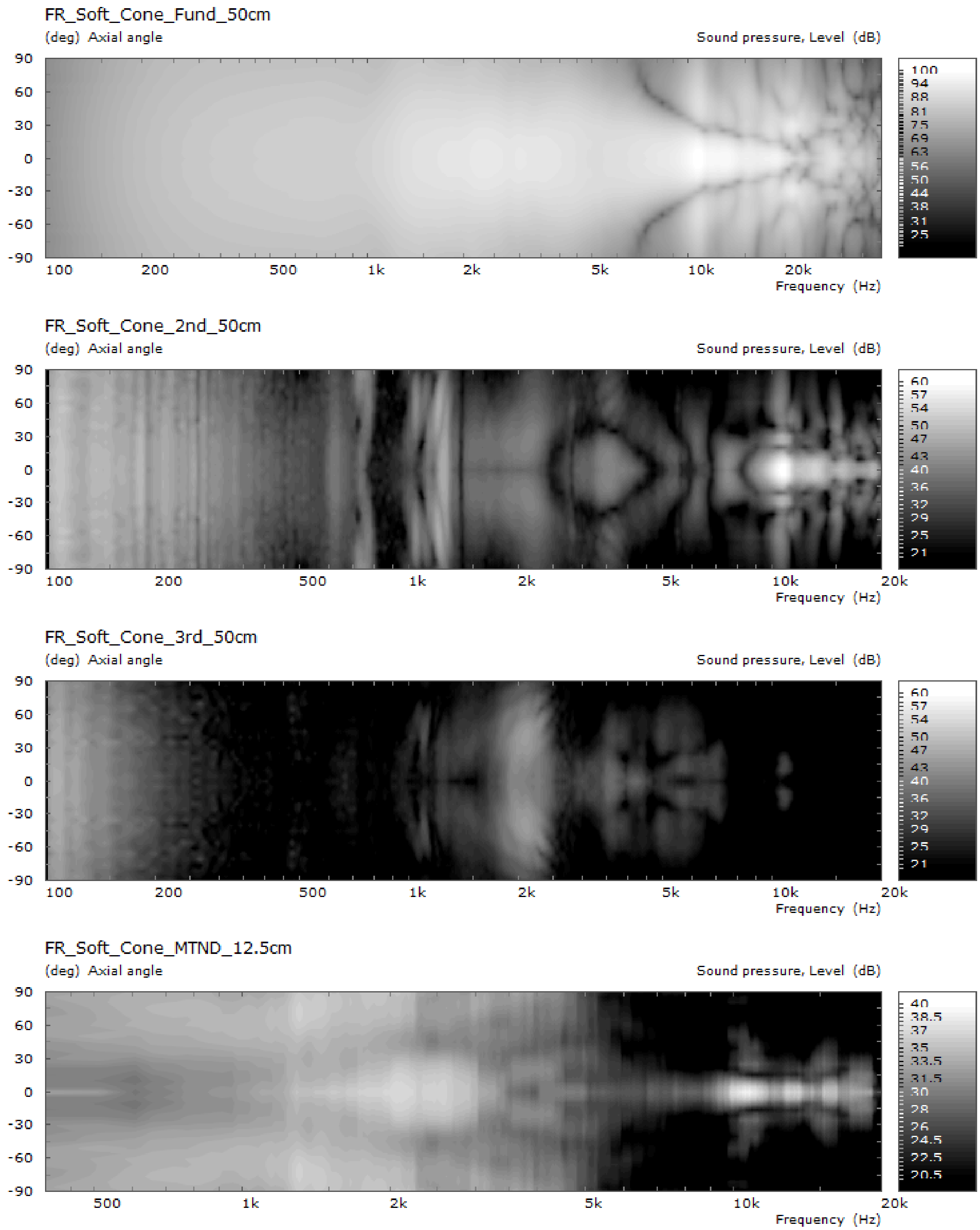

Figure 2: 76mm Full Range Soft Cone

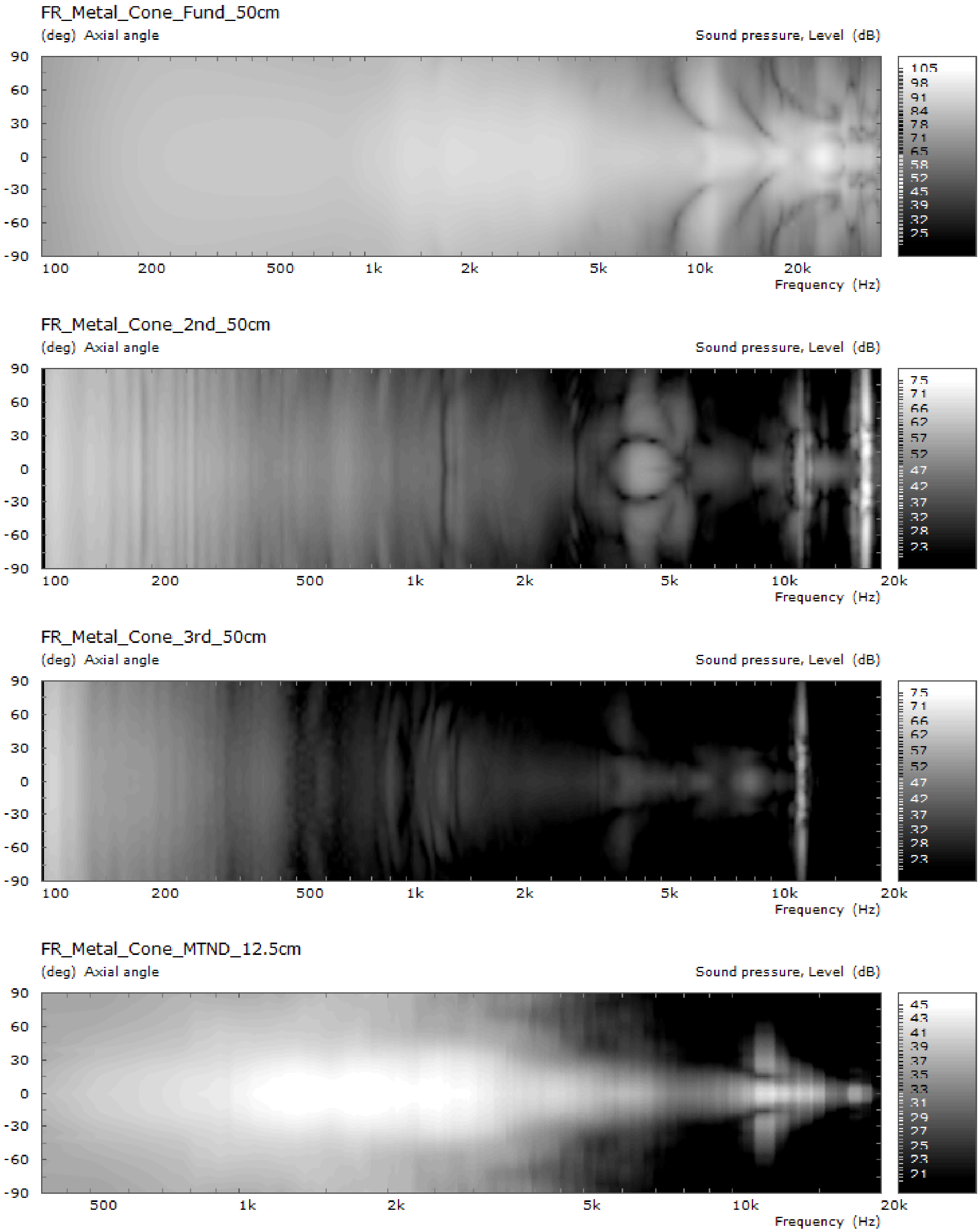

Figure 3: 76mm Full Range Metal Cone

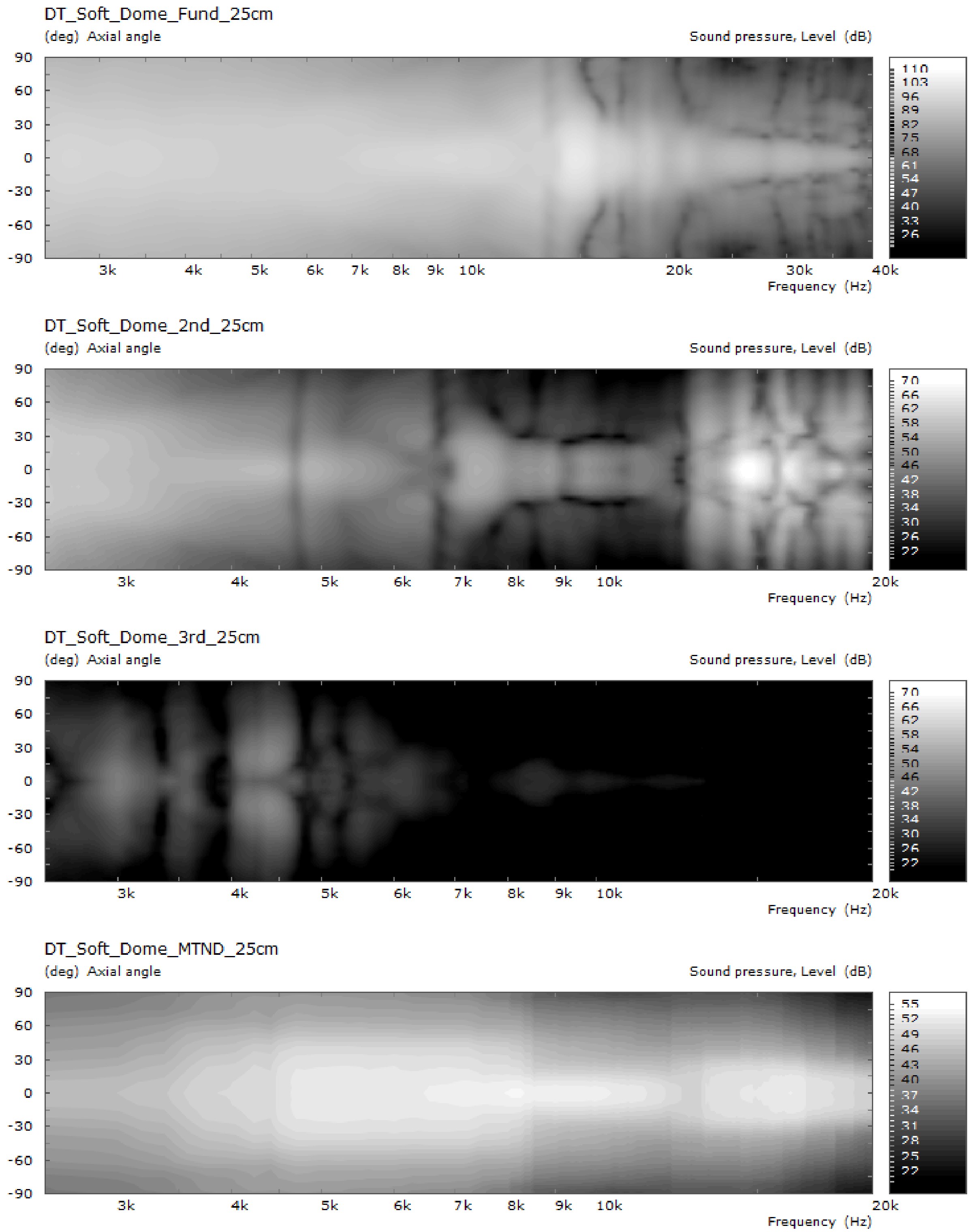

Figure 4: 25mm Soft Dome Tweeter

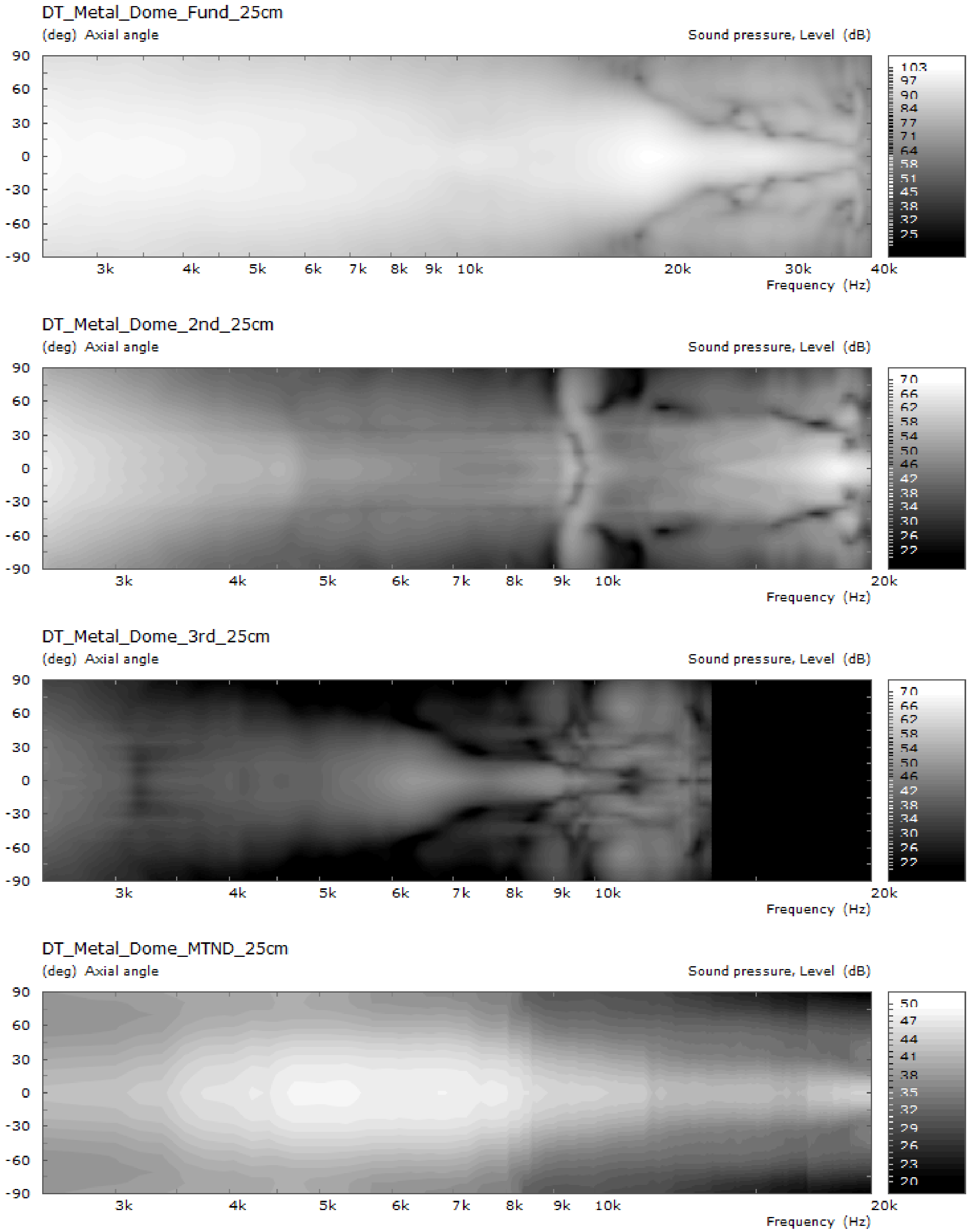

Figure 5: 25mm Metal Dome Tweeter

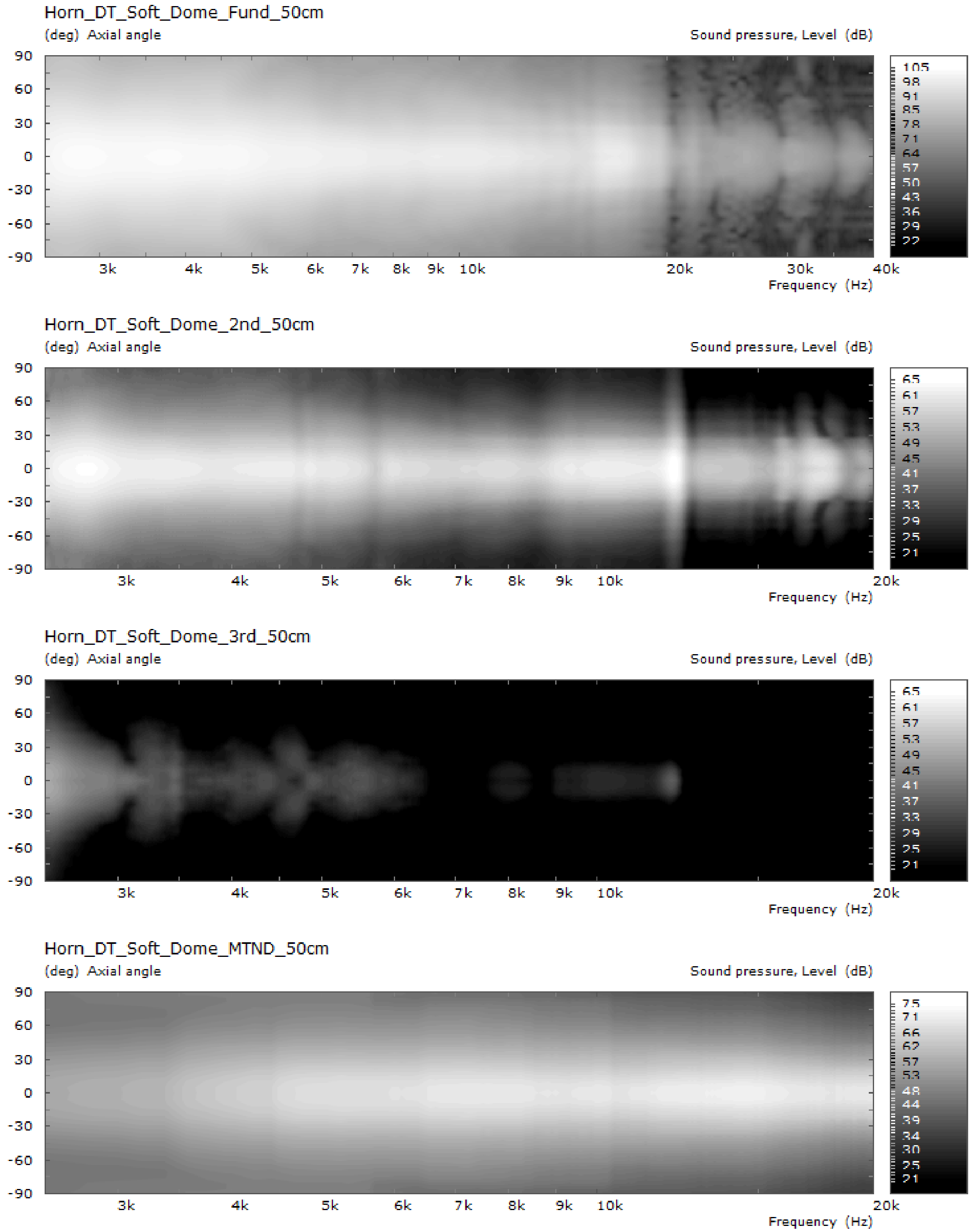

Figure 6: CD Horn 25mm Soft Dome Tweeter

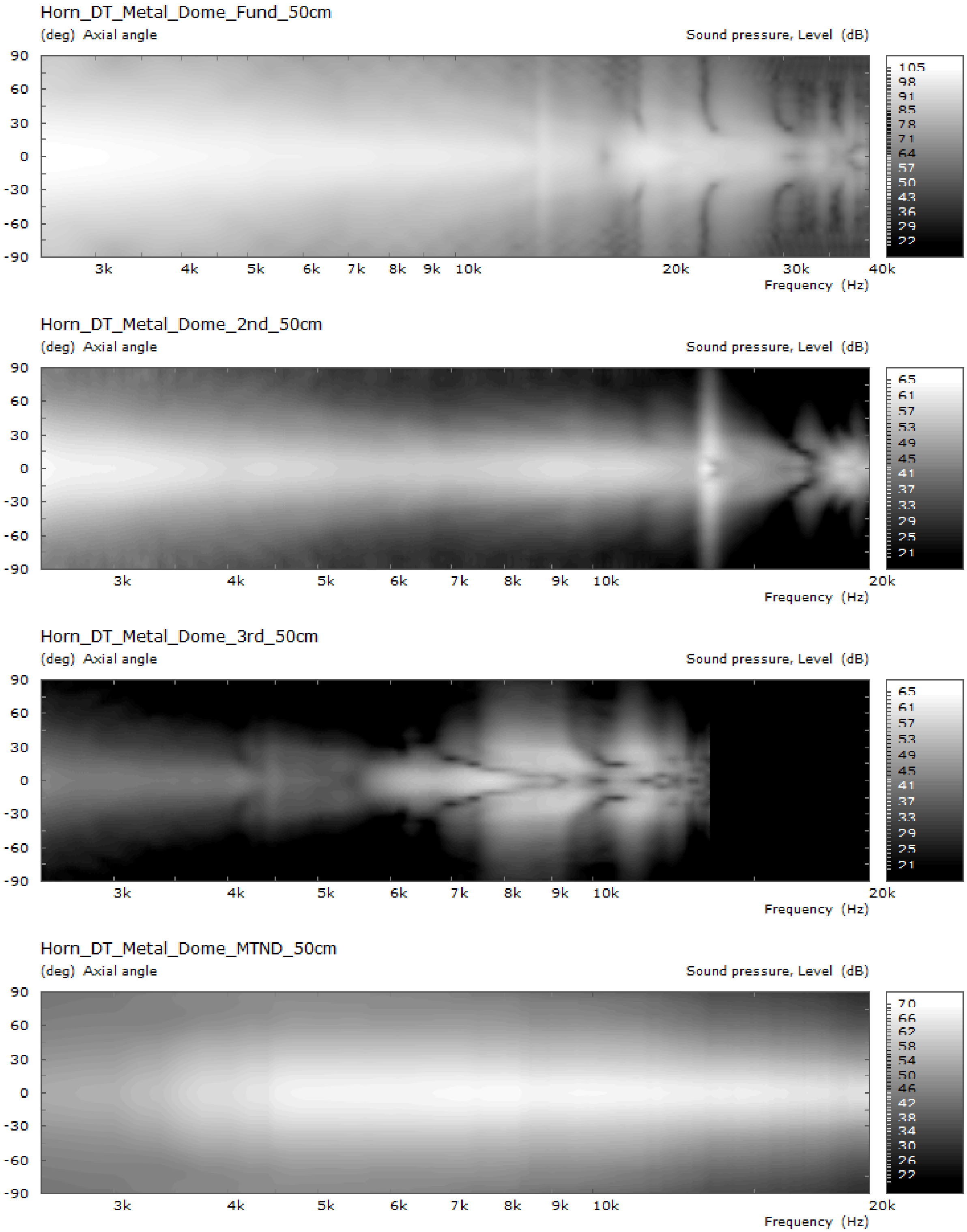

Figure 7: CD Horn 25mm Metal Dome Tweeter

4. CONCLUSIONS

It's quite comforting that MTND products follow fundamental polar pattern, and if the system is of constant directivity type this likely involves that those subjective parameters related to the MTND should be perceived constant among listeners seated at different angles from the axis. For the harmonic distortion the findings of [1] are confirmed and it's also interesting to note how the phasing in horn loaded compression devices is clearly appreciable from 2^{nd} and 3^{rd} polar pattern smoothness.

Future developments in agenda are:

-a correlation of the findings with SCN or laser Doppler analysis of the direct radiating loudspeakers and with distortion causes;

-the use of an anechoic chamber in order to avoid the trade-offs in acquisition time windows and noise floor;

-an extensive analysis of two-way complete loudspeakers of coaxial and non-coaxial type.

5. ACKNOWLEDGEMENTS

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