Preprint 2894 (J3)

On the Audibility of Group Distortion at Low Frequencies

Günter J. Krauss

DYNACORD Electronic und Gerätebau GmbH & Co KG,
Straubing, West Germany

Presented at the 88th Convention 1990 March 13–16 Montreux

AES

AN AUDIO ENGINEERING SOCIETY PREPRINT

On The Audibility Of Group Delay Distortion At Low Frequencies.

Günter J. Krauss

DYNACORD Electronic und Gerätebau GmbH & Co KG
D - 8440 Straubing
West Germany

Abstract

Many books and articles on Electroacoustics tell, that the phase frequency response of an electroacoustic transmission channel does not play an important role concerning the quality of the reproduced sound. Authors often state, that deviations from " Linear phase " do not lead to a perceptible deterioration of the transmitted audio signal. Acoustical comparisons of different audio transmission channels show however, that differences in group delay distortion can clearly be audible at low frequencies. Therefore, the group delay distortion of audio equipment at low frequencies should not be neglected.

1. Introduction

Distortionless transmission through a linear system requires that the amplitude frequency characteristic $|H(\omega)|$ be flat and that the phase frequency response $\phi(\omega)$ is proportional to frequency i.e. $\phi(\omega) = \phi \cdot T$. When the phase response is not linear, phase distortion occurs. One measure of phase distortion, which is interpretable in terms of " spectral thinking ", is the group delay, τ_g, where

$$\tau_g = -\frac{d\phi(\omega)}{d(\omega)}$$

The deviation of the group delay from a constant value in the system passband has been called group delay distortion, $\Delta\tau_g(\omega)$, where

$$\Delta\tau_g(\omega) = \tau_g(\omega) - T$$

and T is the frequency-independent delay in the system [1], [2]. Whether differences in group delay (or group delay distortion) in " real world systems " are perceptible or not is still a controversial discussion in the references. E.g. Bohn [3], Linkwitz [4], Zwicker - Zollner [5], and Bauer [6] state, that phase distortion (or group delay distortion) is not perceptible, except in extreme cases. On the contrary, Baekgard [7] and Fincham [2] suspect group delay distortion as being perceptible. An extensive bibliography on the subject can be found in [1].

Typical electroacoustic building-blocks, e.g. preamplifiers, power amplifiers and equalisers are minimum-phase systems in the audio frequency range. If the overall amplitude frequency response of such systems is flat, they exhibit zero group delay. Some types of published crossover networks are non-minimum phase networks, e.g. the Linkwitz-Riley crossover networks [4]. The summed outputs of the L-R networks form an allpass filter with a flat amplitude frequency response and a non-linear phase frequency response. The users of such equipment often ask, whether the non-linear phase frequency response of those L-R crossover networks can lead to a perceptible deterioration of the audio signal.

2. Experimental Set-Up

Fig.1 shows the experimental set-up which we used for our experiments. A HP 3314A was used as a signal generator. Tone-bursts of different frequencies and a different number of cycles were used. The signals were fed to a " direct path " and an allpass filter. With a selector switch one could compare the direct signal with the output signal of the allpass filter. Electrostatic headphones with a DC amplifier (Stax Lambda Pro, Stax Monitor SRM, diffuse field equaliser bypassed) were used for monitoring. The amplifier-headphone combination is extremely flat down to the lowest audible frequencies.

3. Test Signal

In order to have a direct reference to musical signals, we wanted to avoid " exotic " test signals. Fig.2 show the measured signal of a bass drum. The measurement was made in the far field. The time function of the measured signal shows, that a damped tone-burst is a suitable signal for the simulation. For reasons of simplicity we used a simple tone-burst for the simulation.

3.1 Time Function and Amplitude Spectrum of the Test Signal

Fig.3 and Fig.4 show the time function and the amplitude spectrum of one of the tone-bursts, which we used for our experiments. The amplitude spectrum was calculated with a network analysis program (PSPICE). The spectrum of the tone-burst shows spectral parts above and below the fundamental frequency of the tone-burst. On a linear frequency scale, the minima and maxima are equally spaced. For ease of interpretation we selected a logarithmic scale for both axes.

4. L-R 2 and L-R 4 Networks

The transfer functions of L-R 2 and L-R 4 crossover networks were published in [4]. Fig.5 - Fig.8 serve as an illustration of the phase frequency response and the group delay of the L-R 2 and L-R 4 crossover networks. A crossover frequency of 100 Hz was chosen for the simulation, which is a typical value for subwoofer operation.

5. Linear Distortion of the L-R 2 and L-R 4 Networks

Fig.9 - Fig.11 show a comparison between input and output signals of the summed outputs of L-R 2 and L-R 4 crossover networks. In both cases, the output signals start with a higher frequency and then change over smoothly to the fundamental frequency of the tone-burst. As can be seen from Fig.11, the final value of the output signal of the L-R 2 is reached earlier than for the L-R 4. This behaviour can not be recognized directly from the step response, but can be explained as follows [8].

5.1 Group Delay Distortion

The individual spectral components of the input signal arrive sequentially, delayed by their group delays, at the output and interfere with each other. The signal appears at the output quasi dispersed in time. The time for the build-up of the output signal is approximately equal to the maximum of the group delay of the network [8]. The build-up time lies in the magnitude of the integration time of the ear [9], at least for the L-R 4 crossover network, and should actually be perceptible at the chosen test frequency.

6. Acoustic Comparison of an Allpass-Filtered Signal with an Undistorted Signal

The decisive question is naturally, whether signal distortion visible in the simulation and on the scope can pe percieved at all [5]. Three test persons, of whom we assume that they have average hearing abilities were available for the acoustical tests. When comparing the allpass output signal with the direct signal (see Fig.1), all test persons clearly recognized a difference in sound. The allpass output signal was described as " thin ", " unprecise ", " slightly detuned " compared with the undistorted direct signal. At the beginning of the acoustical tests dynamic headphones were used, in which the sound differences of the allpass-filtered and the direct signal were fundamentally less audible.

7. Summary

L-R 2 and L-R 4 crossover networks were examined analytically. The L-R 4 crossover network summed output transfer function was simulated with a 2^{nd}-order allpass filter. The signal distortion at the beginning and the end of the test signal can be explained by the differing group delays of the spectral components of the test signal. The acoustical comparison between the allpass-filtered and the direct signal clearly show differences in the timbre of the signals. Viewed from the point of view of transfer which is as true to life as possible, it can be determined, that crossover networks with allpass characteristics should be used only, if they introduce no audible deterioration into the signal path. Reference [9] gives a rough idea, what amount of group delay distortion can be tolerated in the vicinity of the crossover frequency.

References :

[1] D.Preis,"Linear Distortion",Journal of the Audio Eng.Soc.,Volume 24,June 1976,Number 5,pp.346-367

[2] L.R.Fincham,"The Subjective Importance Of Uniform Group Delay At Low Frequencies", AES Preprint 2056 (H-1),presented at the 74th AES Convention,1983 October 8-12,New York

[3] D.A.Bohn,"An 8th-Order State-Variable Filter For Linkwitz-Riley Active Crossover Designs, AES Preprint 2697 (B-11),presented at the 85th AES Convention 1988,November 3-6,Los Angeles.

[4] S.H.Linkwitz,"Active Crossover Networks For Noncoincident Drivers",reprinted in AES," An Anthology of articles on Loudspeakers....",AES 1978

[5] E.Zwicker,M.Zollner,"Elektroakustik",2.Auflage, Springer Verlag Berlin,1982

[6] B.B.Bauer,"Audibility of phase distortion",Wireless World,March 1974

[7] E.Baekgard,"A Novel Approach To Linear Phase Loudspeakers Using Passive Crossover Networks",reprinted in AES,"An Anthology of articles on Loudspeakers.....",AES 1978

[8] K.Küpfmüller,"Die Systemtheorie der elektrischen Nachrichtenübertragung",S.Hirzel Verlag Stuttgart, 1974

[9] F.A.Bilsen,I.Kievits,"The minimum integration time of the auditory system",AES Preprint 2746 (B-3), presented at the 86th AES Convention 1989,March 7-10,Hamburg West Germany

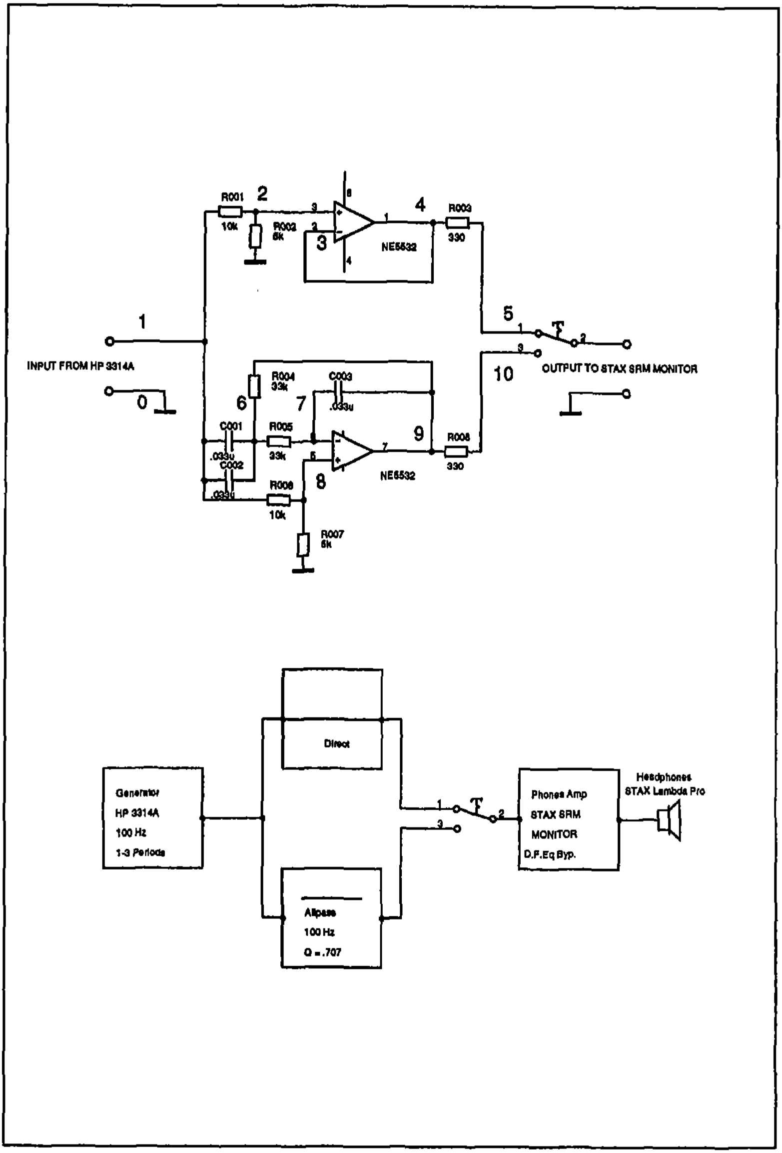

Fig. 1: Principal circuit diagram of the experimental setup

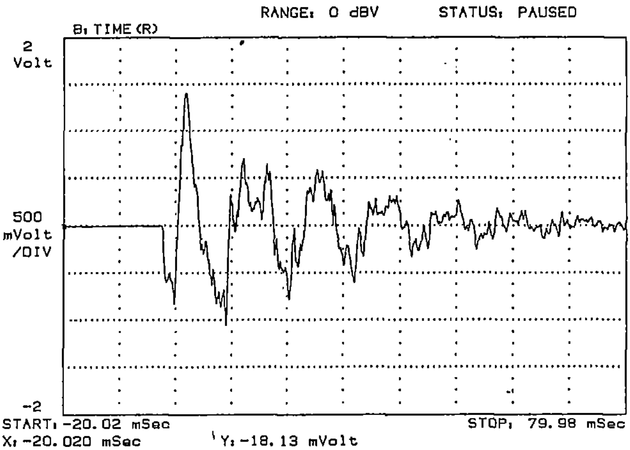

Fig. 2 : Bass drum signal measured in far field

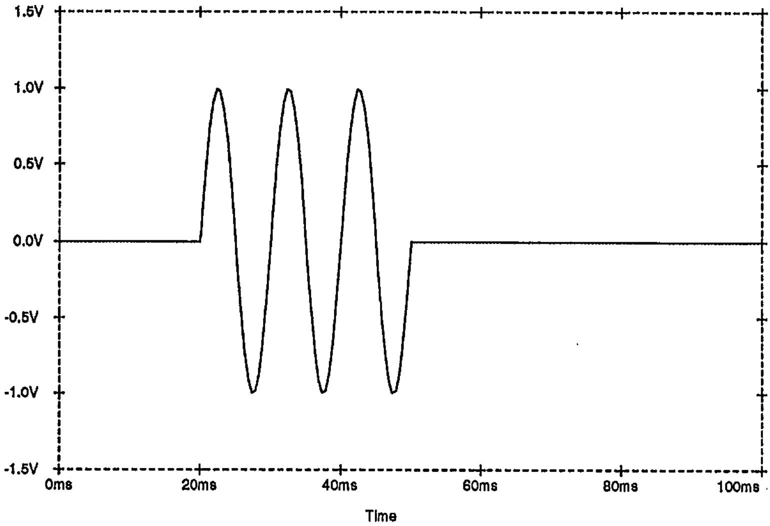

Fig. 3 : Toneburst 100 Hz 3 Periods

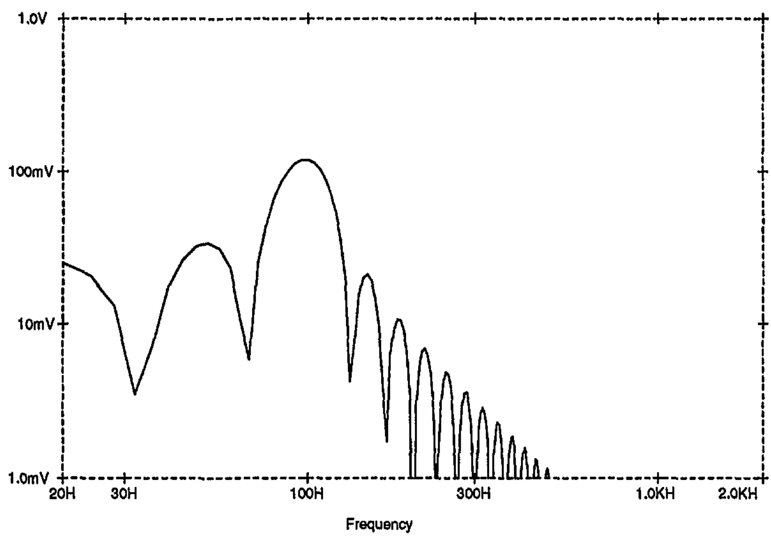

Fig. 4: Amplitude spectrum Toneburst 100Hz 3 Period

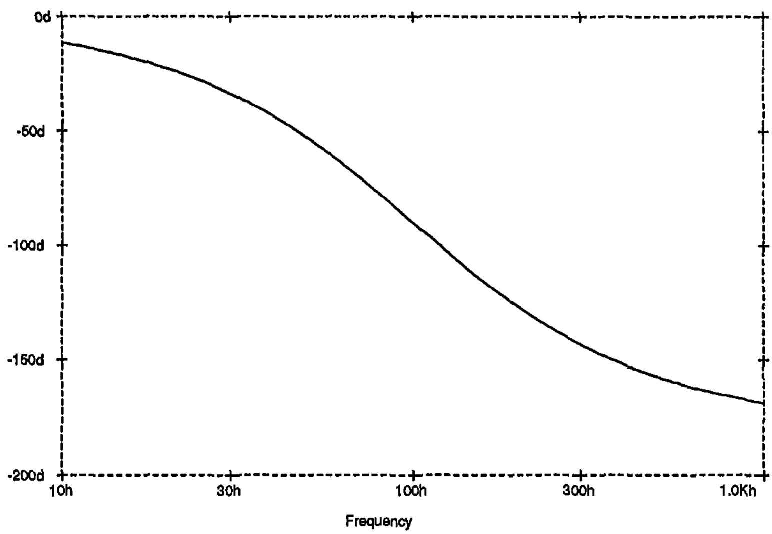

Fig. 5: Phase response LR 2

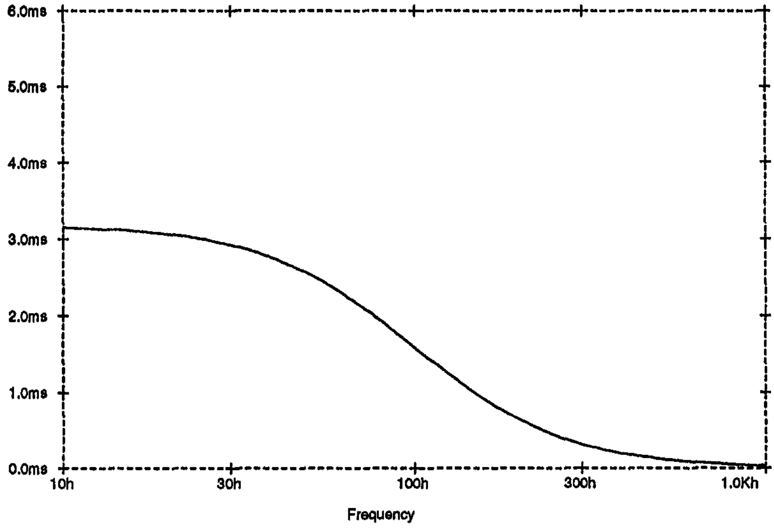

Fig. 6: Group delay LR 2

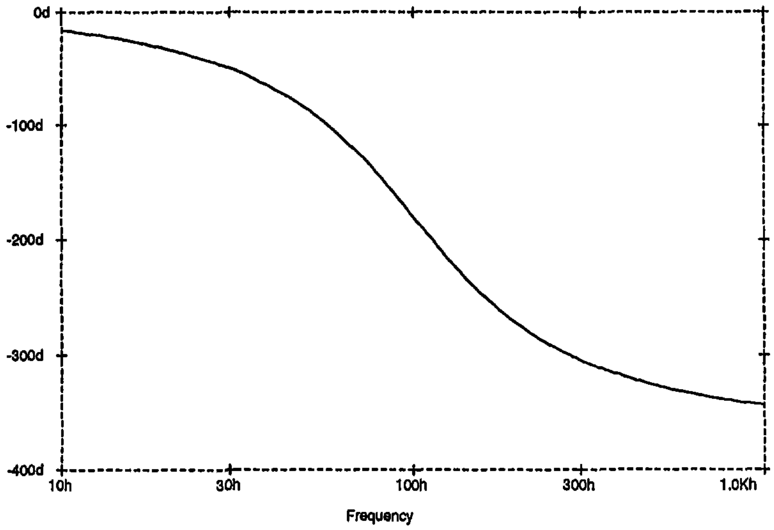

Fig. 7: Phase response LR 4

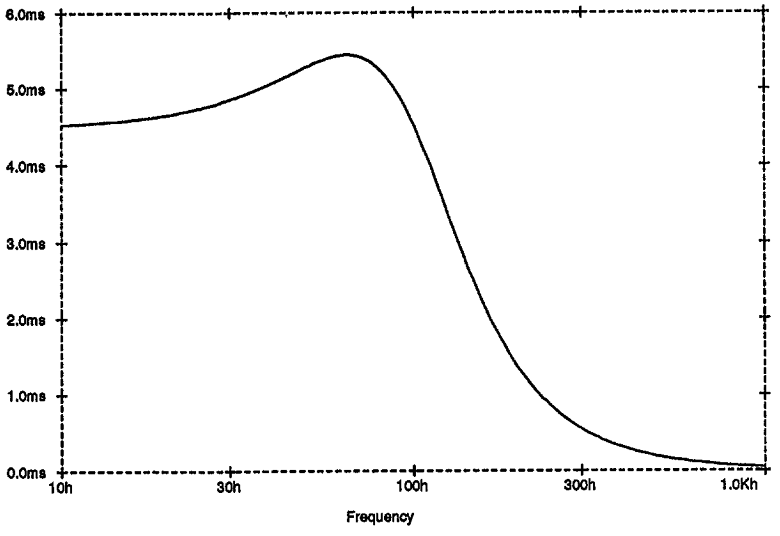

Fig. 8: Group delay LR 4

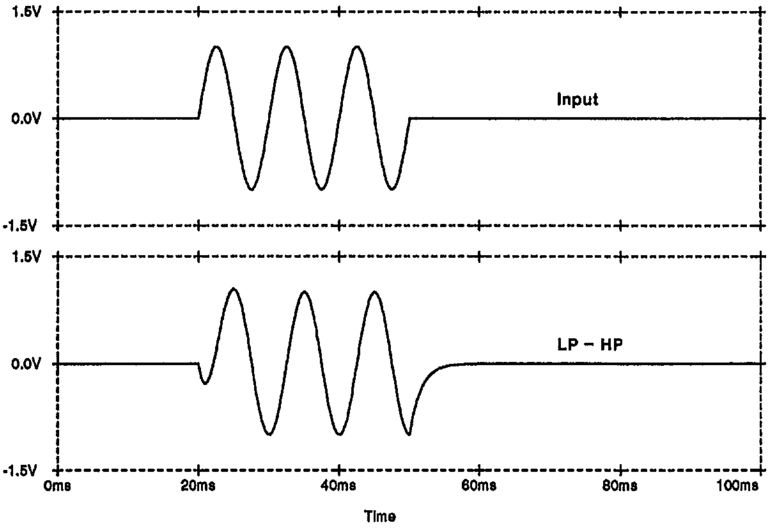

Fig. 9: LR 2 Summed outputs vs Input
f_6 = 100 Hz

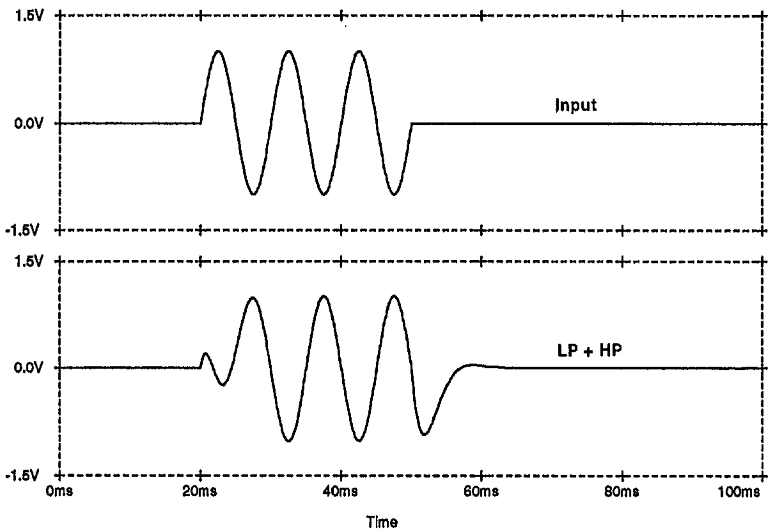

Fig.10: LR 4 Summed outputs vs Input
f_6 = 100 Hz

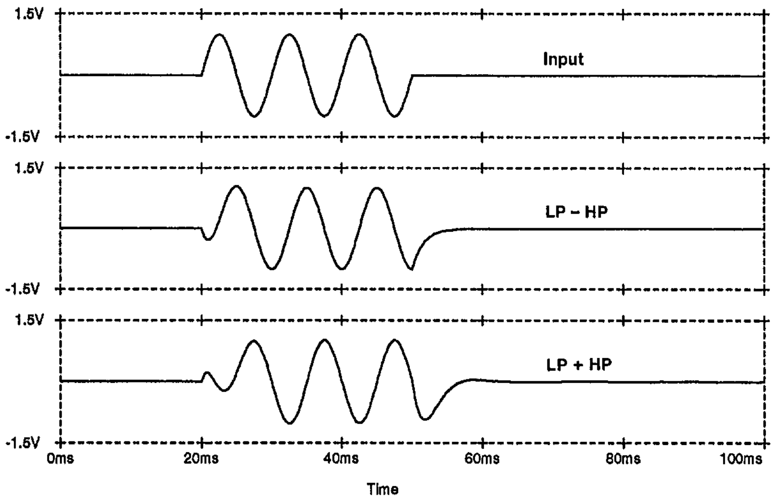

Fig. 11: Direct comparison of summed outputs
LR 2 vs LR 4