Spectral Delay Filters*

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This paper discusses the implementation of spectral delay using filters comprising a cascade of many low-order allpass filters and an equalizing filter. The spectral delay filters have chirp-like impulse responses causing a large, frequency-dependent delay that is useful in audio effects processing. An equalizing filter design and a multirate technique, which stretches the allpass filters, impulse response, are introduced.

0 INTRODUCTION

Filtering an audio signal with an allpass filter does not usually have a major effect on the signal's timbre. The allpass filter does not change the frequency content of the signal, but only introduces a phase shift or delay. Audibility of the phase distortion caused by an allpass filter in a sound reproduction system has been a topic of many studies, see, e.g., [1], [2]. In this paper, we investigate audio effects processing using high-order allpass filters that consist of many cascaded low-order allpass filters. These filters have long chirp-like impulse responses. When audio and music signals are processed with such a filter, remarkable changes are obtained that are similar to the spectral delay effect [3], [4].

1 CHIRP-LIKE IMPULSE RESPONSES AND GROUP DELAY

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$$A(z) = \frac{a_1 + z^{-1}}{1 + a_1 z^{-1}}, \tag{1}$$

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$$\tau_{\mathrm{g,max}} = \begin{cases} \tau_{\mathrm{g}}(0) = \frac{1-a_1}{1+a_1}, \text{when } a_1 \leq 0 \\ \tau_{\mathrm{g}}(\pi) = \frac{1+a_1}{1-a_1}, \text{when } a_1 > 0. \end{cases} \tag{2}$$

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[1] This point is emphasized by Loewer, see esp. p. (610).

1) Green–function determined experimentally and published.
2) Black–function determined using similarity searches and published.
3) Red–function determined using similarity searches and determined in this study.
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Table 1. Active sites and allosteric sites of the GNE MNK enzyme

Excerpt No.	Genre	Spatial Mode	Corrlation
1	Pop	FB	94%
2	Classical	FB	33%
3	Jazz	FF	76%
4	Arabian	FF	41%
5	GNE	H220	45%
6	GNE	H45	93%
7	MNK	G416	74%
8	MNK	D413	72%
9	MNK	R420	94%
10	MNK	N516	91%

Note. This table does not include sentence enhancement statutes. This table does not include sentence enhancement statutes.

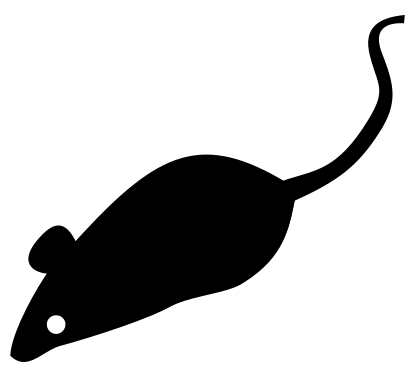

Fig. 1. The spectral delay filter consists of M allpass filters and an equalization filter.

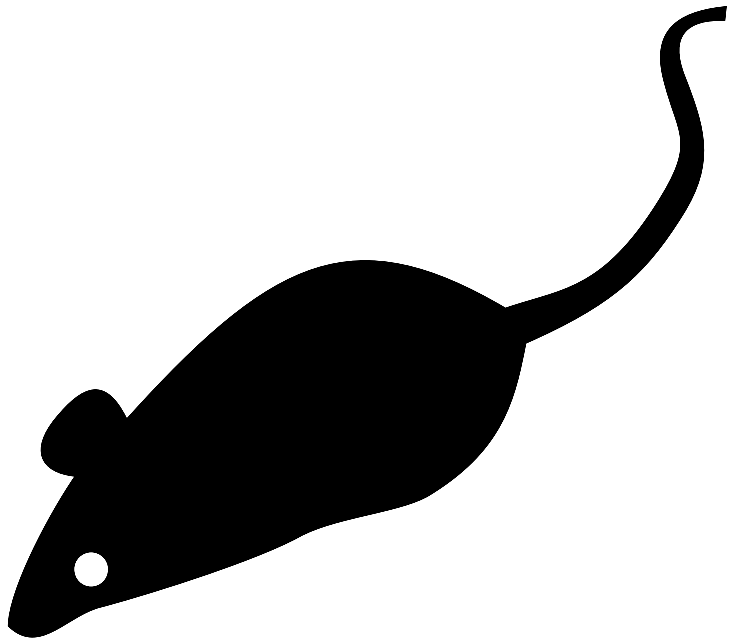

Fig. 2. This paper is organized as follows. In Section 1, we discuss the group delay of a cascade of first-order allpass filters and its relation to the chirp-like impulse response of the spectral delay filter. Furthermore, a multirate method to stretch the impulse response of the spectral delay filter is proposed. Section 2 discusses the amplitude envelope of the impulse response and suggests a design method for the equalizing filter. Section 3 presents application examples using the spectral delay filter. Section 4 concludes this paper.

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$$\tau g(\omega) = -\frac{d\phi(\omega)}{d\omega}.$$

Audibility of the phase distortion caused by an allpass filter in a sound reproduction system has been a topic of many studies, see, e.g., [1], [2]. In this paper, we investigate audio effects processing using high-order allpass filters that consist of many cascaded low-order allpass filters. These filters have long chirp-like impulse responses. When audio and music signals are processed with such a filter, remarkable changes are obtained that are similar to the spectral delay effect.

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2 SUMMARY

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3 CONCLUSION

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4 ACKNOWLEDGMENT

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APPENDIX

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$$\phi(\omega) = -\omega + 2\arctan\left(\frac{a_1 \sin\omega}{1 + a_1 \cos\omega}\right) \tag{1}$$

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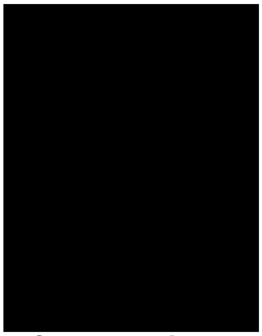
NOMENCLATURE

a_c = condensation coefficient condensation coefficient condensation coefficient

TLR = Toll-like receptor

PAMPs = pathogen-associated molecular patterns condensation coefficient condensation

THE AUTHORS



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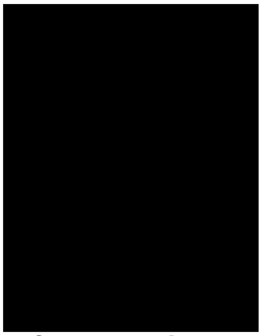

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As an industry consultant, Abel has worked with Apple, FDNY, LSI Logic, NRL, SAIC and Sennheiser, on projects in professional audio, GPS, medical imaging, passive sonar and fire department resource allocation. He holds Ph.D. and M.S. degrees from Stanford University, and an S.B. from MIT, all in electrical engineering. Abel is a Fellow of the Audio Engineering Society.