# Non-Uniform Filterbanks for Digital Audio Effects

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## 1 Abstract

This project will explore the possibilities of building audio effects based on non-uniform filter banks. The end goal is to produce four effects in the form of audio plugins:

1. Multiband dynamics meter: A metering plugin that splits the spectrum into 10 critical frequency bands. The plugin will show the peak and RMS gain of each band in real time. This sort of plugin will be useful for mixing and mastering engineers in analyzing the dynamic range of a song in individual frequency bands.

2. Mastering Graphic EQ: In mastering, it is often desireable to use linear phase filters for equalization with reduced phase distortion. Most graphic equalizers, on the other hand, introduce some amount of phase distortion, since they do not use perfect reconstruction (PR) filterbanks. The idea here is to create a "mastering quality" graphic EQ, through the implementation of a PR non-uniform filterbank. Note that unlike the metering plugin, this effect will require both analysis and synthesis filterbanks.

3. Frequency "Sound-A-Like" effect: In mixing, it can sometimes be be useful to make two instruments sound nearly identical. To that end, this plugin will accept a "sidechain" input, and will filter the main input so that the frequency spectra of the two channels are identical. Note that this will require an analysis and synthesis filterbank for the main input, as well as an additional analysis filterbank for the sidechain input.

4. Frequency "Separator" effect: A more common case in mixing is that the engineer has two tracks with similar frequency spectra, and wishes to "separate" the two tracks spectrally, so that the listener can distinguish more easily between the two. This plugin will function as an inverse to the "Sound-A-Like" plugin.

A brief discussion of non-uniform filterbanking techniques is given below, followed by signal flow diagrams for each individual plugin.

## 2 Non-Uniform Fliterbank Techniques

- Polyphase filterbank [1]: For this method, a filterbank would be designed as a set of minimum-phase bandpass filters $H_k(z)$, as well as the set of inverse filters $F_k(z)$. Each analysis filter can then be deconstructed using a "type 1" polyphase representation:

$$H_k(z) = \sum_{l=0}^{N-1} z^{-l} E_{kl}(z^N) \tag{1}$$

  And each synthesis filter can be deconstructed as "type 2" polyphase:

$$F_k(z) = \sum_{l=0}^{N-1} z^{-N-l-1} R_{lk}(z^N) \tag{2}$$

Using polyphase matrices $E(z)$ and $R(z)$, we can achieve perfect, in-phase reconstruction with reasonable efficiency. Note that it is necessary for the set of analysis filters to be minimum-phase to ensure that the inverse filters are causal and stable.

In some implementations, such as [2], the polyphase method is used to create a uniform PR filterbank, then the channels are aggregated so as to generate a non-uniform filterbank. However, it should be possible to achieve greater efficiency by beginning with non-uniform filters.

- Constant-Q transform: Alternatively, a constant Q transform could be used to generate the filterbank.

$$X(k) = \frac{1}{N(k)} \sum_{n=0}^{N(k)-1} W(k,n)x(n)e^{\frac{-j2\pi Qn}{N(k)}} \tag{3}$$

where $W(k,n)$ is a windowing function, and

$$N(k) = Q\frac{f_s}{f_k} \tag{4}$$

[3] gives a framework for invertible, real-time Constant-Q Transforms (CQTs), using non-stationary Gabor frames. [4] discusses a specific real-time implementation of a 48 point invertible CQT, in the context of a pitch-shifting effect.

# 3 Multiband Dynamics Meter

A signal flow diagram for the Multiband Dynamics Meter can be seen in fig. 1. Note that since this effect is a meter, no signal reconsntruction is required. The visualizer will display both peak and RMS gains for each channel.

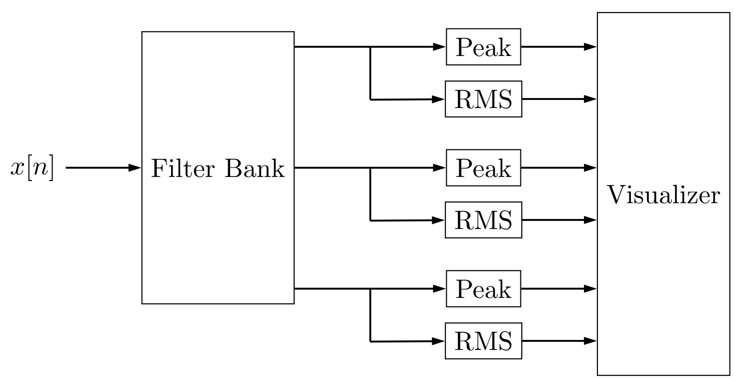


Figure 1: *Multiband Dynamics Meter signal flow, shown here with 3 channels.*

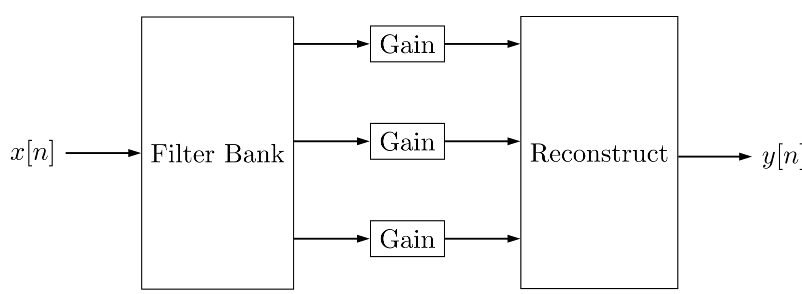


Figure 2: *Signal flow for Graphic EQ.*

# 4 Mastering Graphic EQ

Signal flow for the Mastering Graphic EQ can be seen in fig. 2. Since the gain operators will only affect the amplitude of each channel, if the filter bank has perfect reconstruction, the output should not introduce any phase distortion.

# 5 Frequency "Sound-A-Like" and Separator

The "Sound-A-Like" and Separator plugins will function similarly, with a detector filter bank on the sidechain input (fig. 3), and an automatic gain control filterbank, followed by a reconstruction filterbank on the main input (fig. 4). The detector output for each channel of the sidechain filterbank will provide "key" the input for the automatic gain control on the corresponding channel of the main filterbank. The only difference between the two plugins will be the gain computers implemented in each plugin's automatic gain control processors.

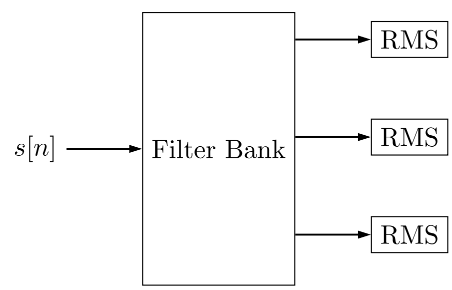


Figure 3: *Signal flow for sidechain input.*

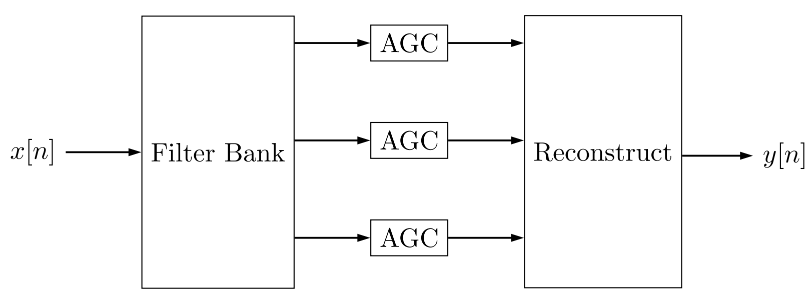


Figure 4: *Signal flow for main input.*

# References


[1] Julius O. Smith, *Spectral Audio Signal Processing*, accessed 4/13/2019, online book, 2011 edition.

[2] S Kumar and M Rao, "M-band graphic equalizer," *International Journal on Computer Science and Engineering*, vol. 3, pp. 2955–2964, 08 2011.

[3] Nicki Holighaus, Monika Doerfler, Gino Angelo Velasco, and Thomas Grill, "A framework for invertible, real-time constant-q transforms," *IEEE Transactions on Audio, Speech and Language Processing*, vol. 21, 09 2012.

[4] Christian Schörkhuber, Anssi Klapuri, and Alois Sontacchi, "Audio pitch shifting using the constant-q transform," *Journal of the Audio Engineering Society*, vol. 61, pp. 562–572, 07 2013.