Barberpole Phasing and Flanging Illusions

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Project

Implement a time-varying barberpole phaser based on the cascaded notch filters suggested by Esqueda, Välimäki, and Parker (2015)

Barber-poles

Barber-poles

- Image attached to a rotating cylinder
- Cycle, but it is difficult to detect the beginning of the cycle
- Creates a visual illusion of stripes ascending forever

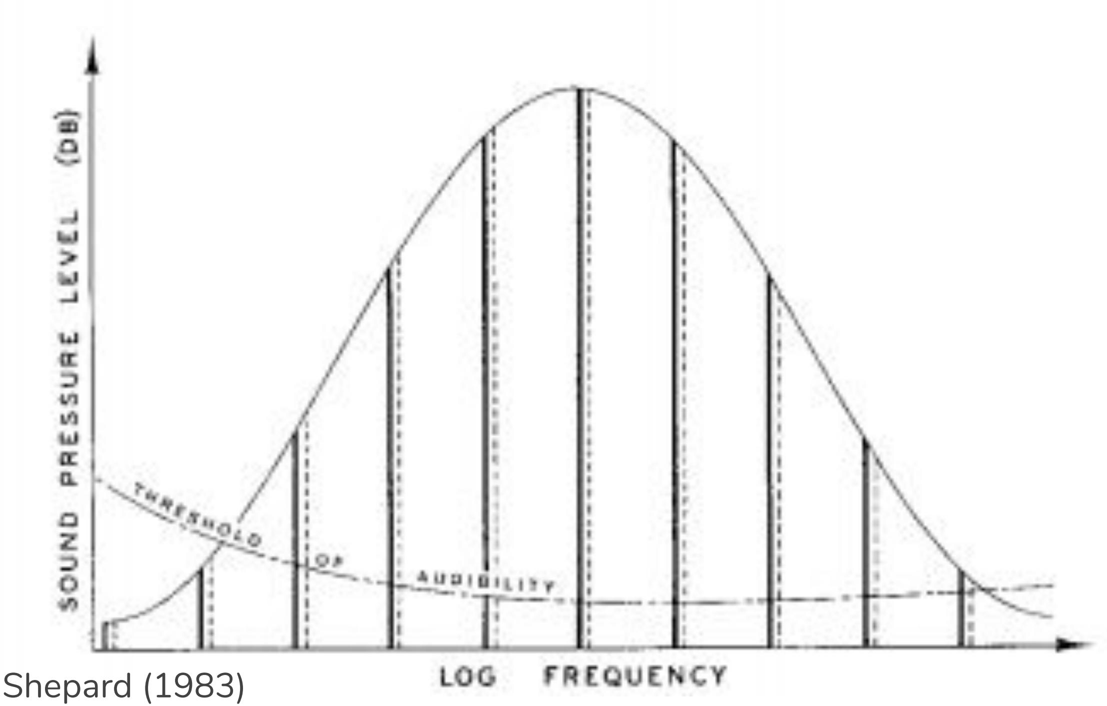
Shepard's ascending chromatic scale

Source: Shepard (1983)

How to achieve the audio illusion

1. We need several harmonics **one octave apart**
2. The harmonics in the middle must be **louder** than the ones at the beginning or end of the frequency spectrum
3. We need to change the gain of each harmonic as time goes on, for example, using some spectral envelope

Shepard Tones



Source: Shepard (1983)

Barber-Pole Phasing and Flanging Illusions (Esqueda, Valimaki, and Parker 2015)

- Three systems for producing barber-pole audio effects
  - Cascaded time-varying notch filters
  - Synchronized dual flanger
  - Single-sideband modulation

How to achieve the audio illusion

1. We need several **notches one octave apart**
2. The **notches** in the middle must be **softer** than the ones at the beginning or end of the frequency spectrum
3. We need to change the gain of each of the **notches** as time goes on, for example, using some spectral envelope

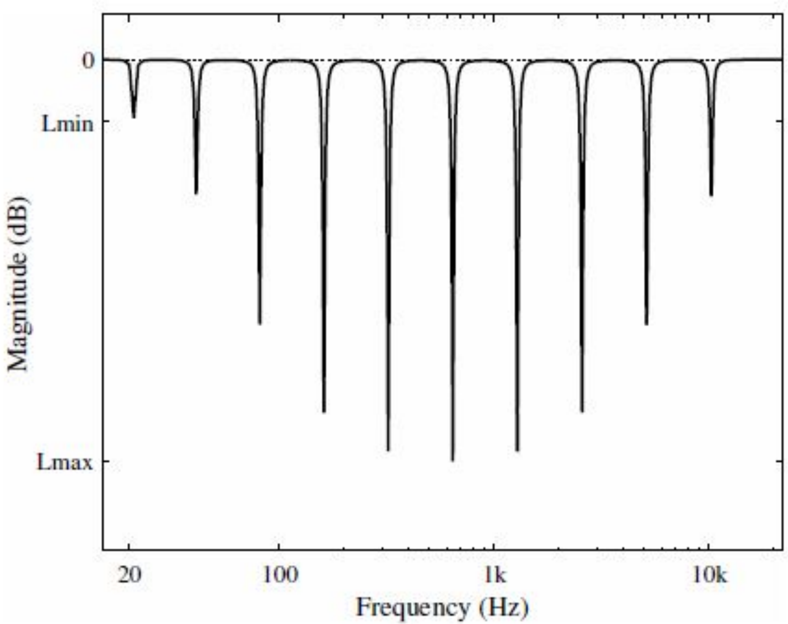
Cascaded time-varying notch filters

Synchronized dual flanger

Single-sideband modulation

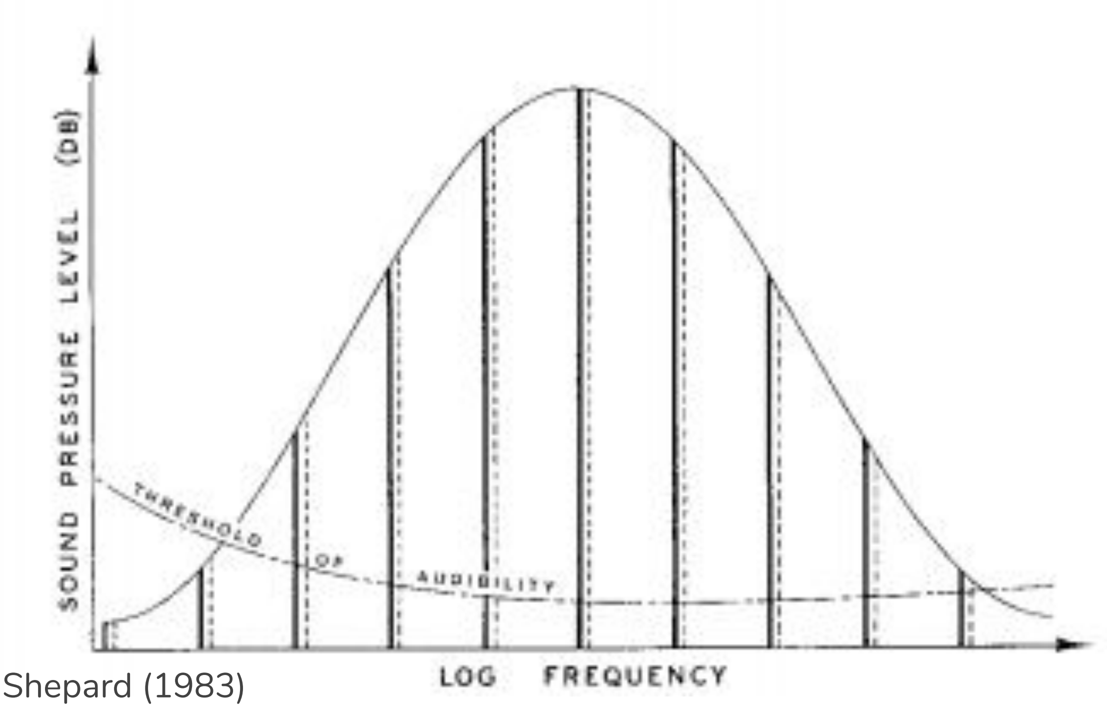
Implementation of cascaded notch-filters

Cascaded time-varying notch filters



Source: Esqueda, Valimaki, and Parker (2015)

Shepard Tones



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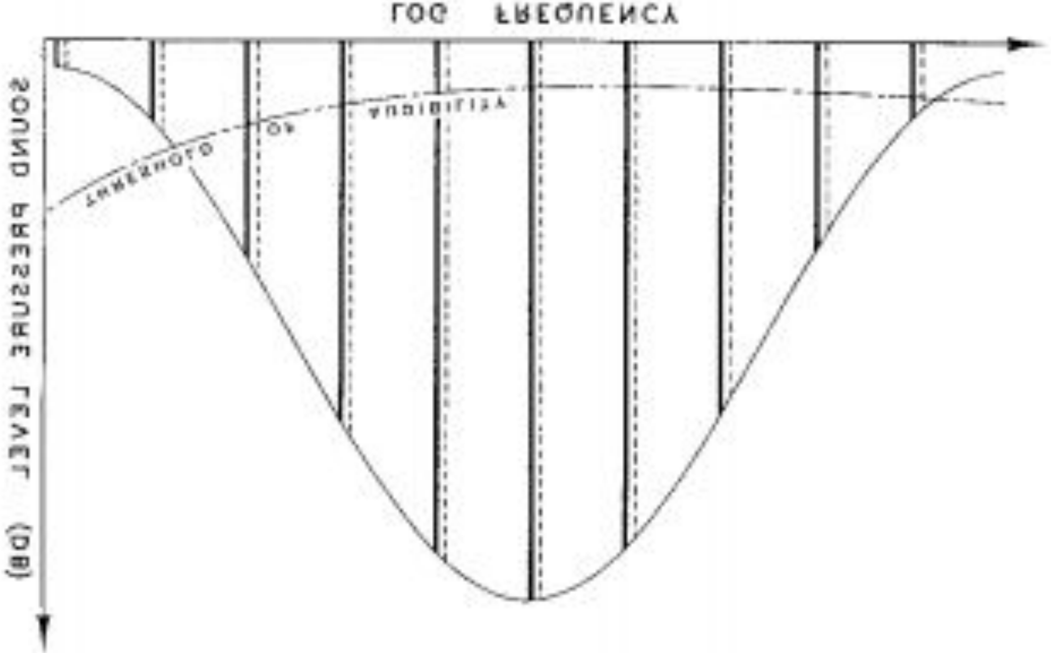
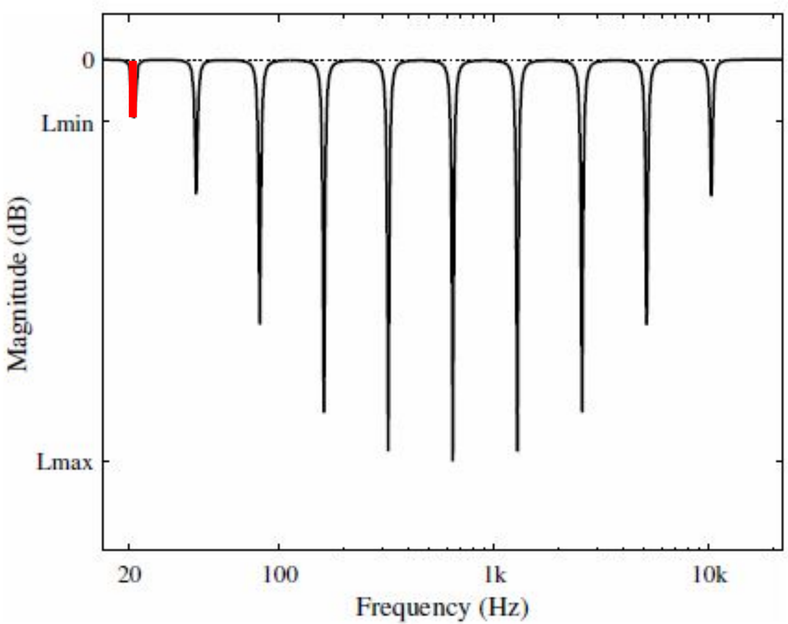


Source: Shepard (1983)

Cascaded time-varying notch filters



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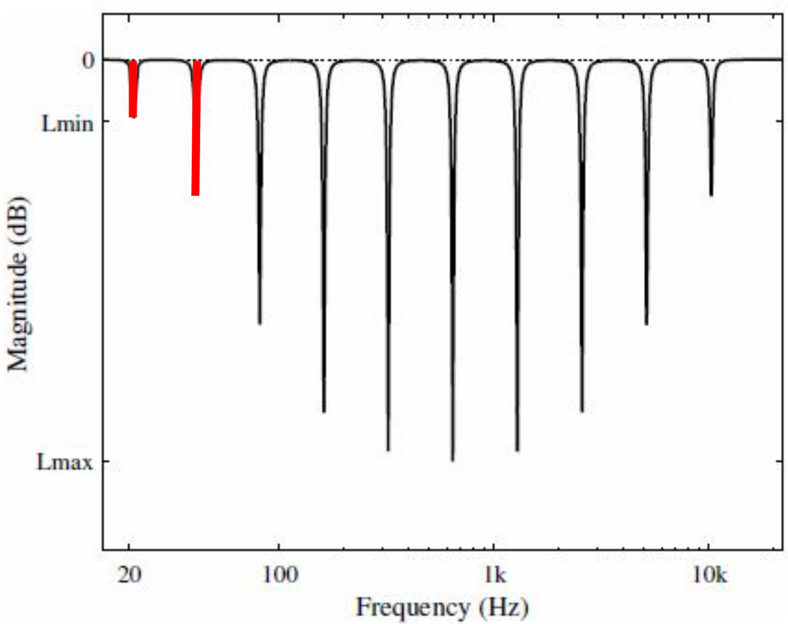
Cascaded time-varying notch filters



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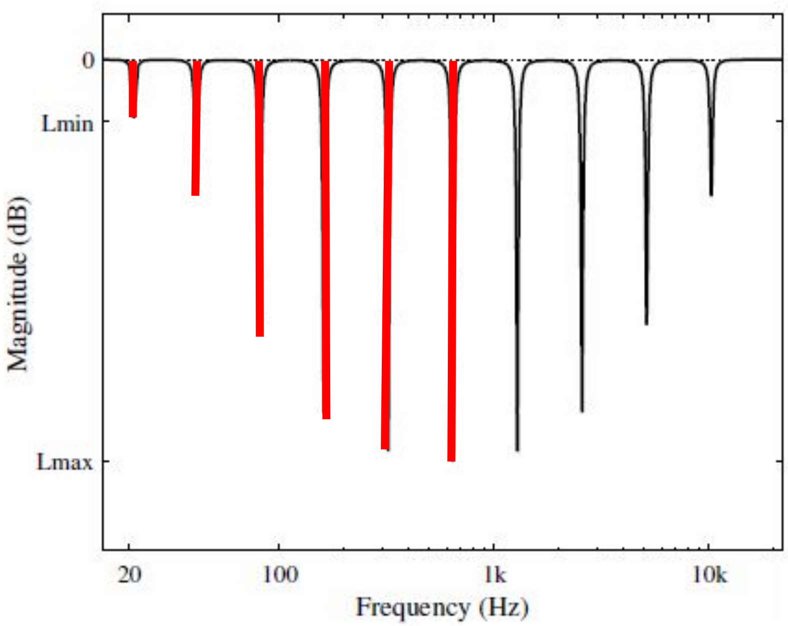
Cascaded time-varying notch filters



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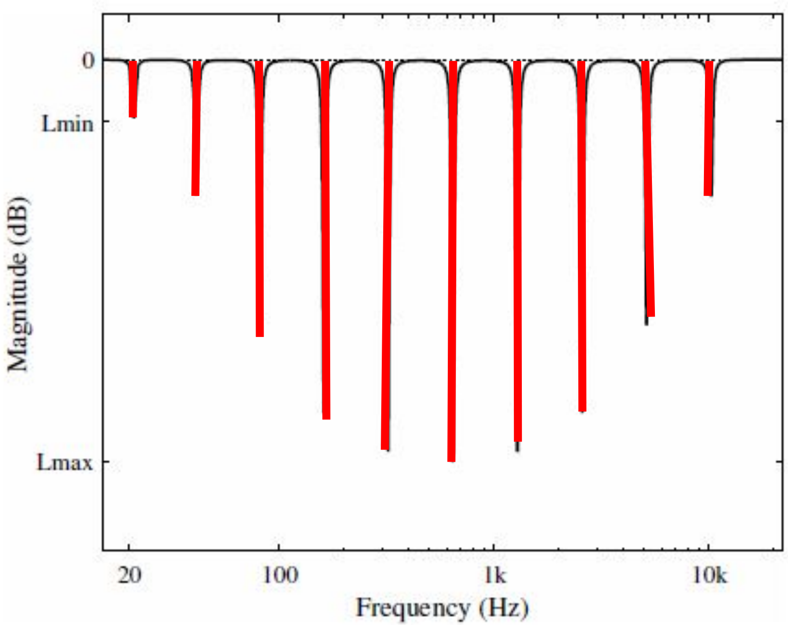

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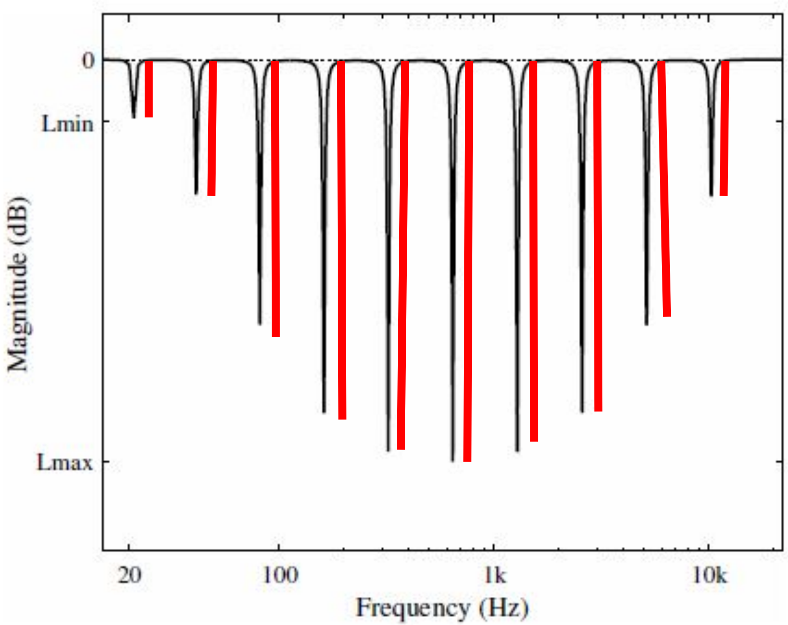
Cascaded time-varying notch filters



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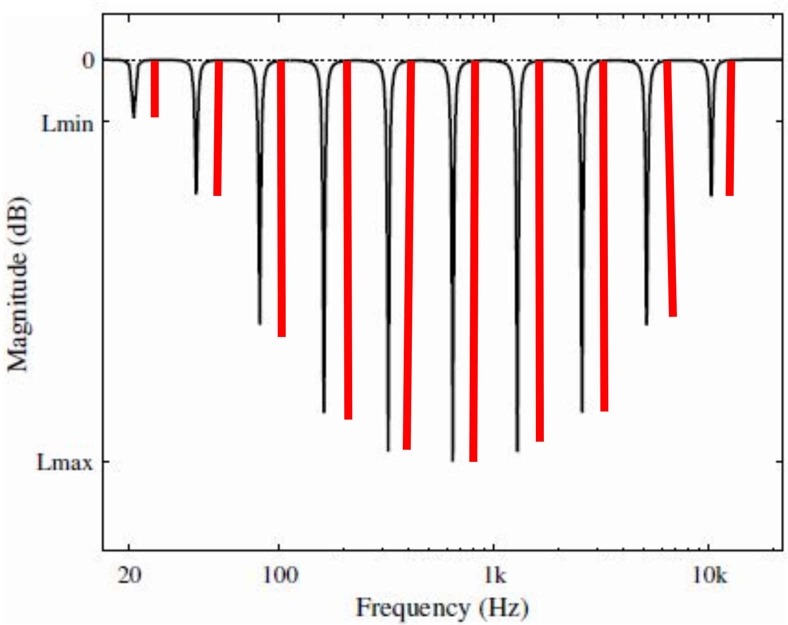
Cascaded time-varying notch filters



Source: Esqueda, Valimaki, and Parker (2015)

Strategy for implementation

The paper provides the equations for each relevant parameter, but does not explicitly explain which aspects are time-varying and which are global to the system

- Separate parameters
  - Global
  - Time-varying

Global parameters

- **M**
  - Number of notch-filters
- **Fs**
  - Sampling rate
- **K**
  - Frequencies per cycle, for every filter
- **Q**
  - Used to control the bandwidth of a notch filter
- **p**
  - Repetition rate of the cycle in Hz (how many times are we reaching an octave every second)
- **Lmin, Lmax**
  - Minimum and maximum loudness of the notch filters (dB)

Time-varying parameters (change every sample)

- **fc(m,k)**
  - Center frequency (Hz) for the m-th filter in the k-th frequency index of the cycle
- **Lc(m,k)**
  - Loudness for the k-th frequency of the m-th filter (dB)
- **G**
  - Normalized gain of Lc [0.0 ,1.0]
- **β**
  - Factor that involves the bandwidth and the normalized gain at the bandwidth when computing the coefficients of the filter

Time-varying parameters (change every sample)

$$f_c(m, k) = f_0 2^{[K(m-1)+k-1]/K}$$

Time-varying parameters (change every sample)

$$f_c(m,k) = f_0 2^{[K(m-1)+k-1]/K]}$$

$$\text{semitone}(s, f_0) = f_0 2^{s/12}$$

Time-varying parameters (change every sample)

$$L_c(m,k) = L_{min} + \frac{(L_{max} - L_{min})(1 - cos[\theta(m,k)])}{2}$$

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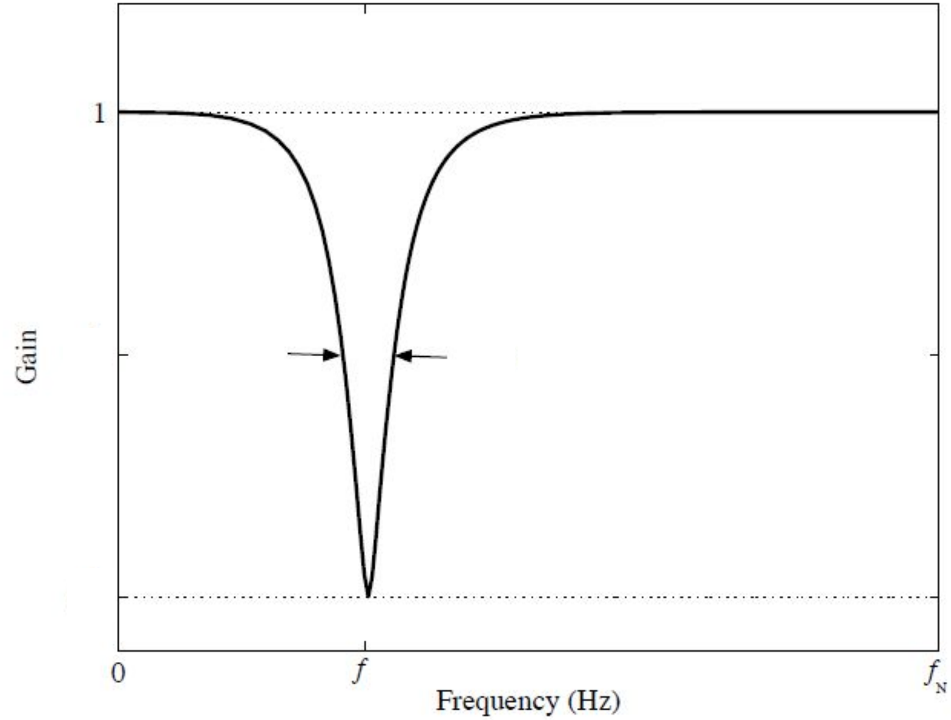
$$L_c(m,k) = L_{min} + \frac{(L_{max} - L_{min})(1 - cos[\theta(m,k)])}{2}$$

$$G = 10^{L_c(m,k)/20}$$

Time-varying parameters (change every sample)



Source: Esqueda, Valimaki, and Parker (2015)

Transfer function for m-th filter in k-th frequency index

$$H(z) = \frac{\left(\frac{1+G\beta}{1+\beta}\right) - 2\left(\frac{\cos(\frac{2\pi f_c}{F_s})}{1+\beta}\right) z^{-1} + \left(\frac{1-G\beta}{1+\beta}\right) z^{-2}}{1 - 2\left(\frac{\cos(\frac{2\pi f_c}{F_s})}{1+\beta}\right) z^{-1} + \left(\frac{1-\beta}{1+\beta}\right) z^{-2}}$$

Transfer function for m-th filter in k-th frequency index

$$y[n] = b_0 x[n] - b_1 x[n-1] + b_2 x[n-2] + a_1 y[n-1] - a_2 y[n-2]$$

Demo

Conclusions

- Implementation of a cascaded notch-filter system to create auditory illusions from an input signal
- The reference paper was very informative about the parameters used to test the filter and generate the sound samples and the plots
- Some inconsistencies in the definitions made me tweak and interpret some of the parameters

Thank you