Laguerre Warped Filters for Ambisonic Imaging

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Overview

- Introduction
- Antecedents (Prior Art)
- Ambisonic Encoding
- Warped Comb Filters & Resulting Spreading Network
- Image Control
- *Effects*
- Pros and cons
- Summary
- Listening & Discussion

Introduction

- Goal: synthesize spatially complex Ambisonic images
- Musically useful?
  - Presumably...
  - Need “scales” to create musical contrasts / meaning
- How do we generate...
  - Complex soundfields?
  - Immersive soundfields?
  - Active sound fields?
- How do we control?
  - Less complex
  - Less imersive
  - Less active

Antecedents

- Gerzon “Spreaders”
  - Frequency dependent Ambisonic panners
  - Phase compensated Unitary feedback technique: “Difficult”
- Menzies
  - LAmb
  - W-Panning
  - *(we can ask the man...)*

Ambisonic Encoding

Basic 3D...

...as a function of Time...

…as a function of Frequency...

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \cos\phi\cos\theta \\ \cos\phi\sin\theta \\ \sin\phi \end{pmatrix}$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \cos\phi_t\cos\theta_t \\ \cos\phi_t\sin\theta_t \\ \sin\phi_t \end{pmatrix}$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \cos\phi_f\cos\theta_f \\ \cos\phi_f\sin\theta_f \\ \sin\phi_f \end{pmatrix}$$

Ambisonic Encoding

Basic 2D...

…as a function of Frequency...

…so need to find 3 filters...

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \cos\theta \\ \sin\theta \end{pmatrix}$$

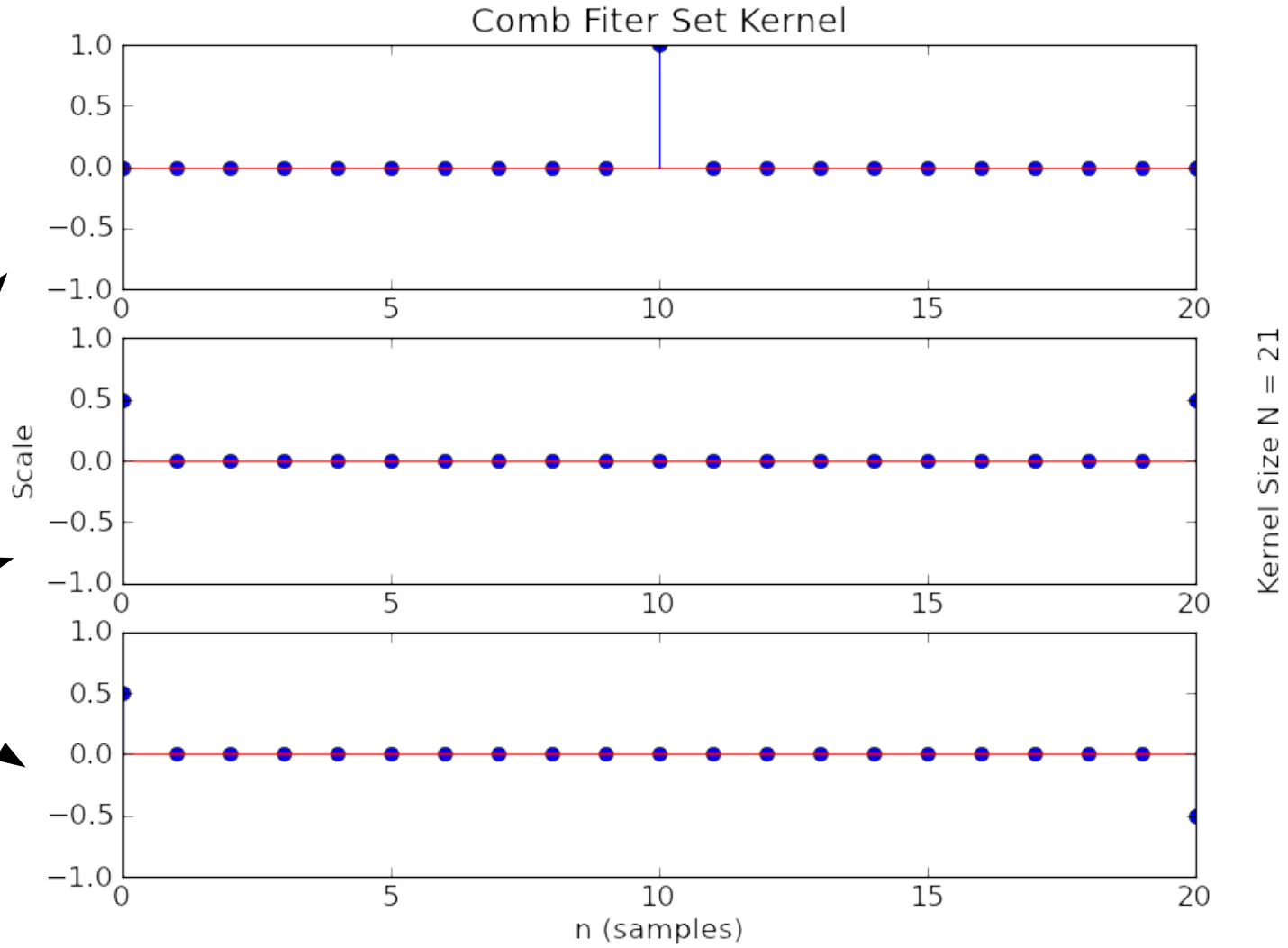
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \cos\theta_f \\ \sin\theta_f \end{pmatrix}$$

$$\begin{pmatrix} e^{-j\frac{N\omega_f T}{2}} \\ e^{-j\frac{N\omega_f T}{2}}\cos\left(\frac{N\omega_f T}{2}\right) \\ -je^{-j\frac{N\omega_f T}{2}}\sin\left(\frac{N\omega_f T}{2}\right) \end{pmatrix}$$

Comb Filter Set

Prototype
Filter Kernel

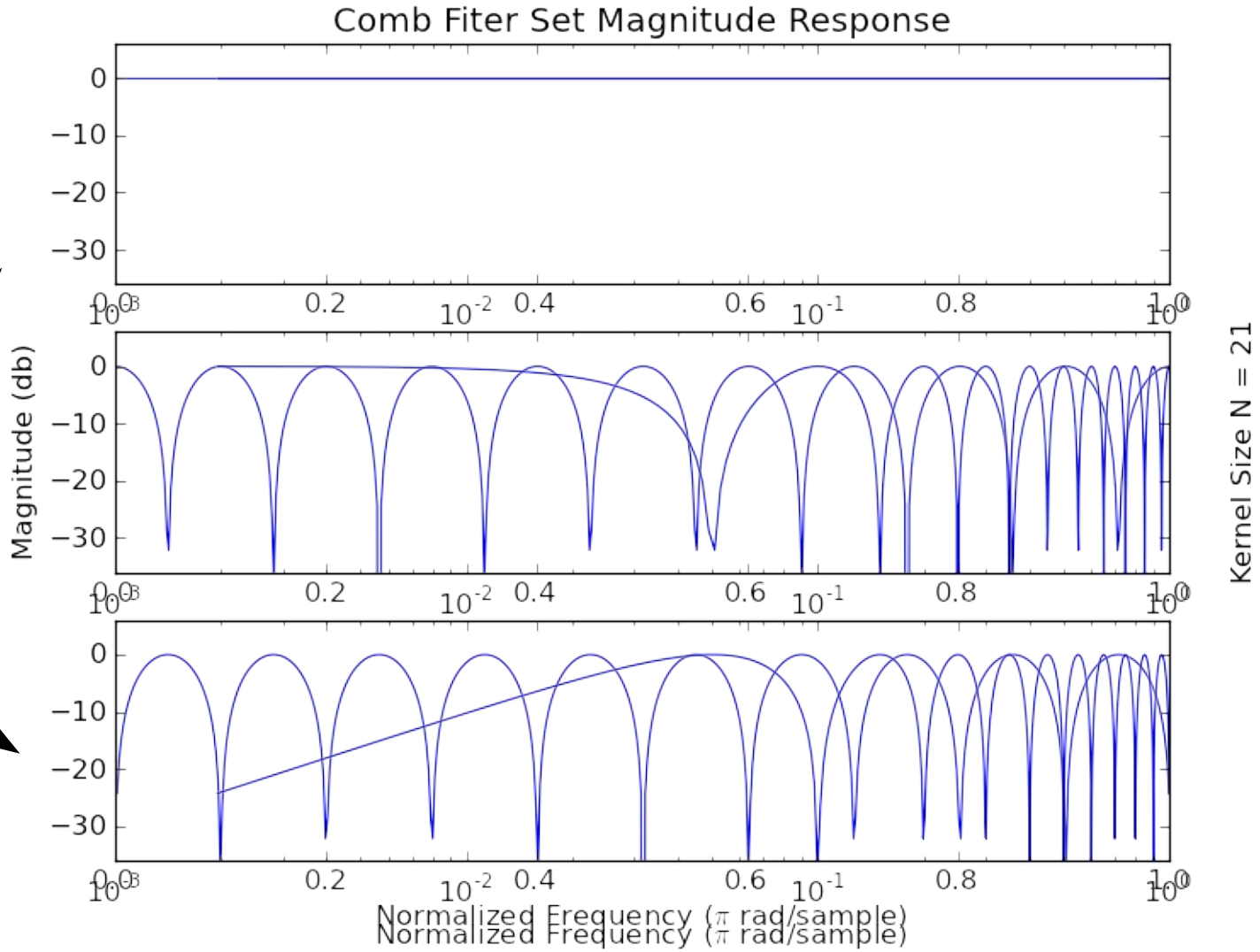
$$\begin{pmatrix} e^{-jN\pi f/f_s} \\ e^{-jN\pi f/f_s}\cos\left(N\pi f/f_s\right) \\ -je^{-jN\pi f/f_s}\sin\left(N\pi f/f_s\right) \end{pmatrix}$$



Comb Filter Set

Prototype Magnitude

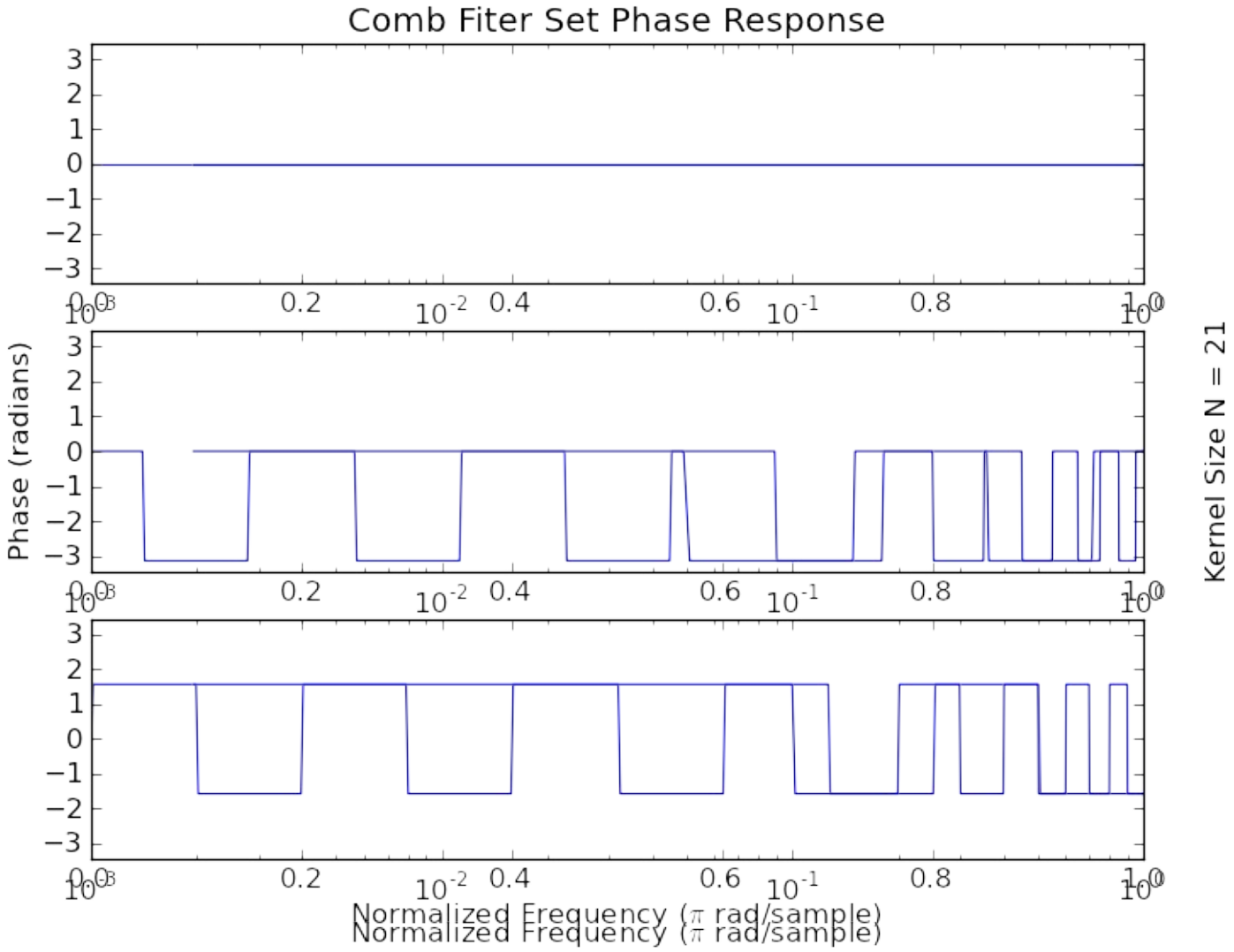
$$\begin{pmatrix} e^{-jN\pi f/f_s} \\ e^{-jN\pi f/f_s}\cos\left(N\pi f/f_s\right) \\ -je^{-jN\pi f/f_s}\sin\left(N\pi f/f_s\right) \end{pmatrix}$$



Comb Filter Set

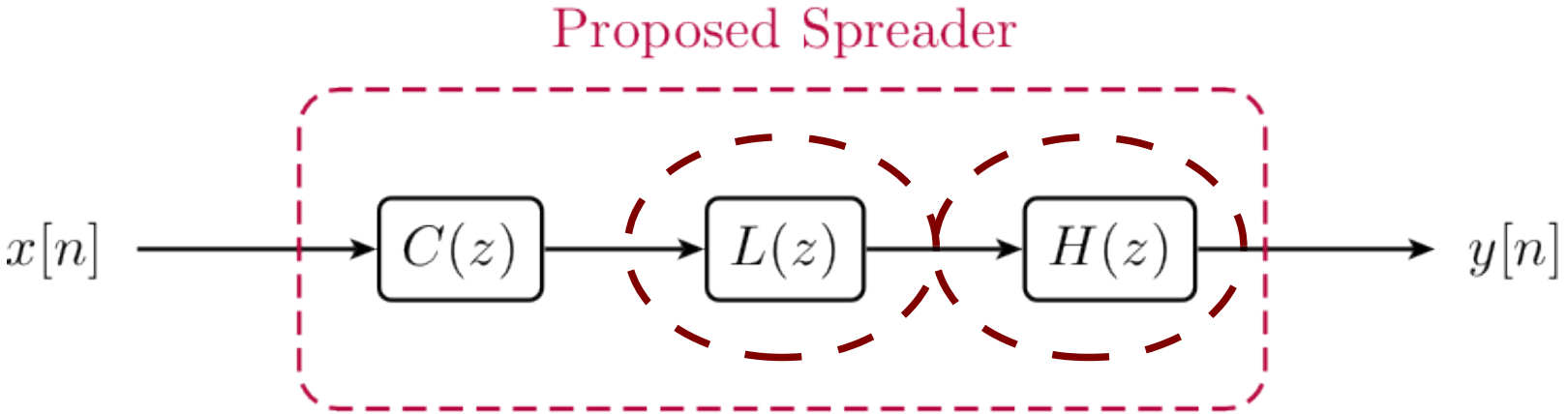
Prototype Phase

$$\begin{pmatrix} e^{-jN\pi f/f_s} \\ e^{-jN\pi f/f_s}\cos\left(N\pi f/f_s\right) \\ -je^{-jN\pi f/f_s}\sin\left(N\pi f/f_s\right) \end{pmatrix}$$



Comb Filter Set

- A good start, but...
  - Magnitude response is linear rather than logarithmic.
  - Sine filter has “nasty” *j* term, i.e., is 90° out of phase.
- … luckily we can fix by...
  - Frequency warping with the Laguerre Transform
  - Phase shifting with the Hilbert Transform

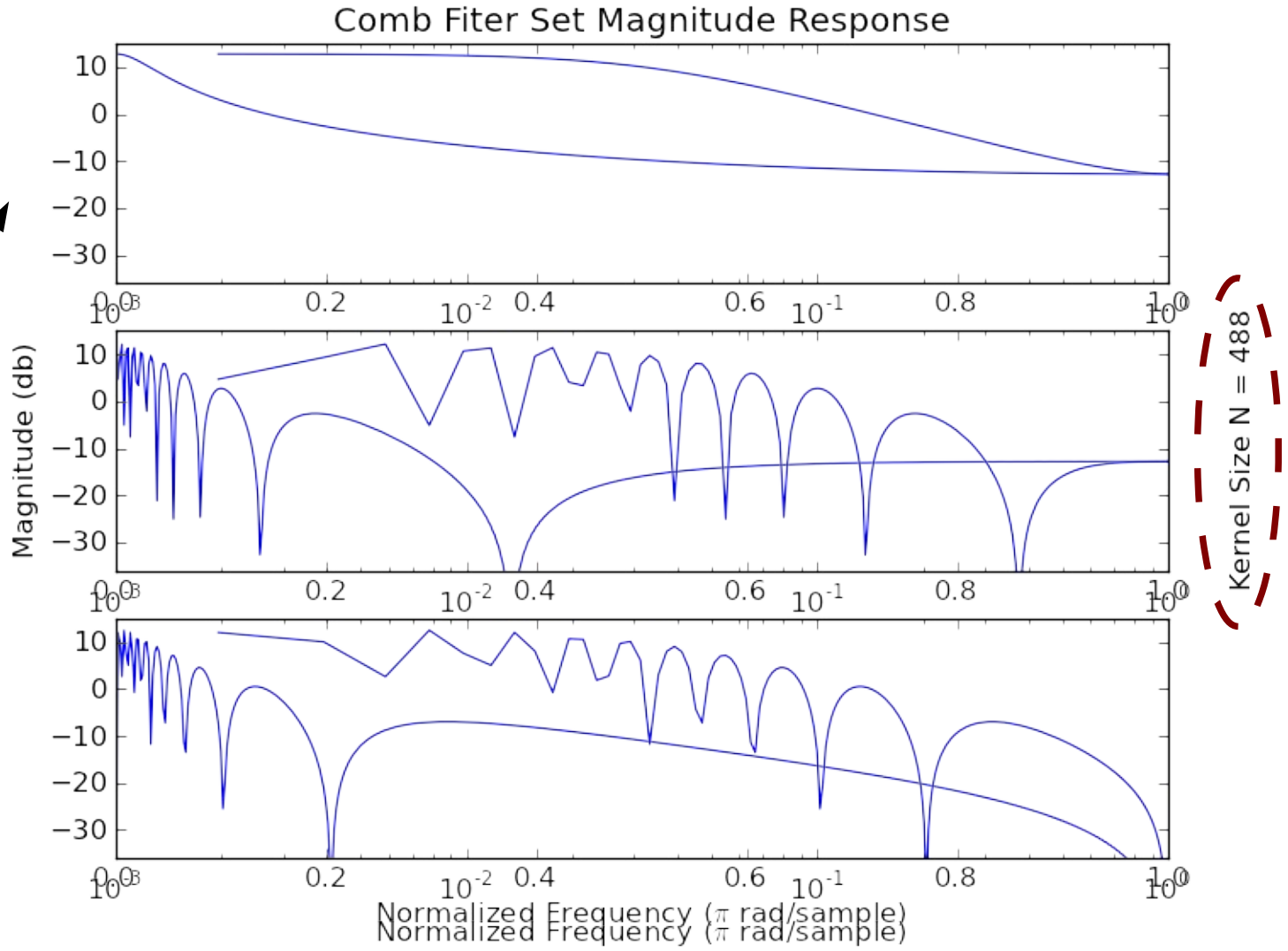


Warped Comb Filter Set

Warped Magnitude

c = .9

No longer all-pass!

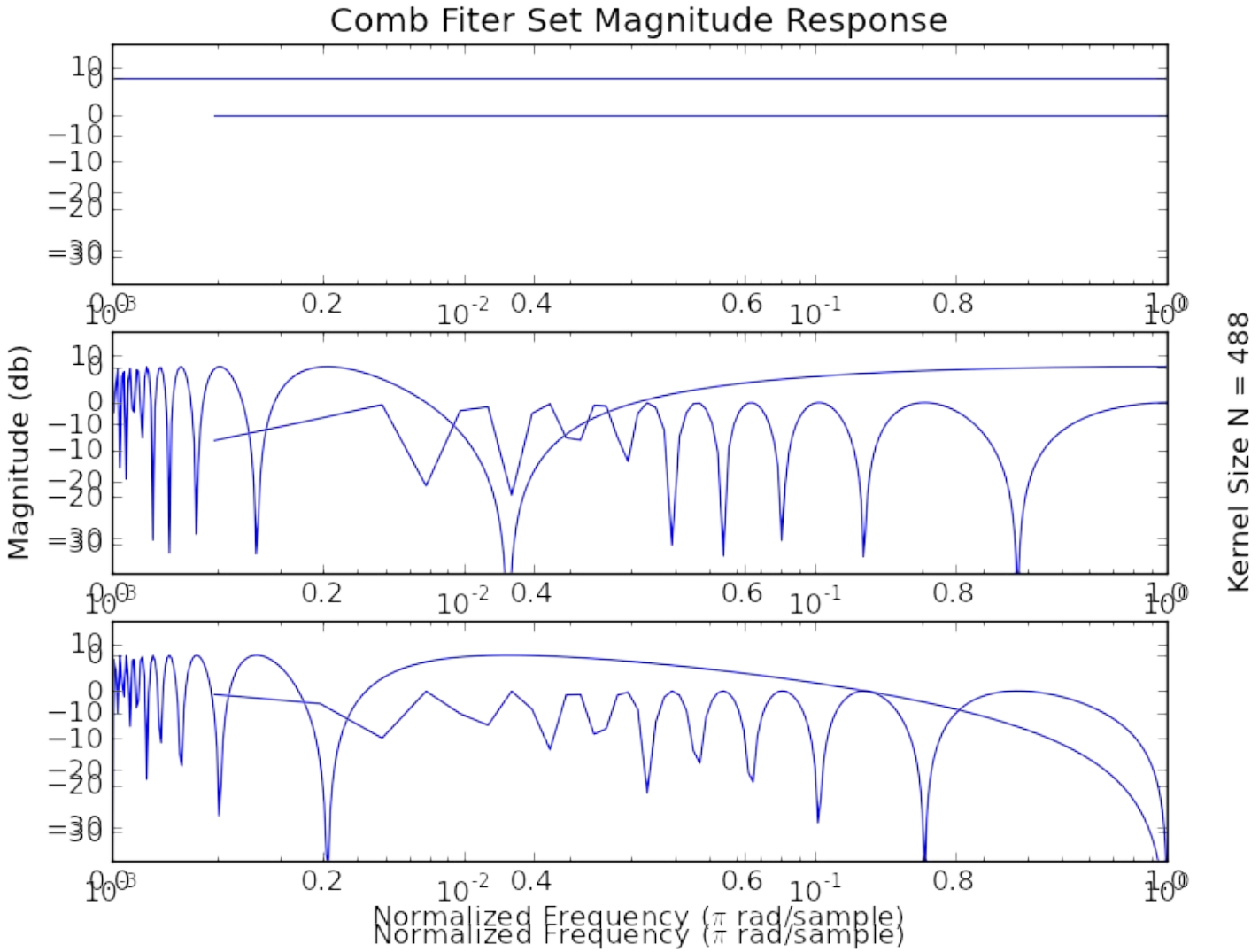


Warped Comb Filter Set

Warped Magnitude, Equalised

c = .9

$$\mathbf{EQ}(z) = \frac{1 - cz^{-1}}{\sqrt{1 - c^2}}$$



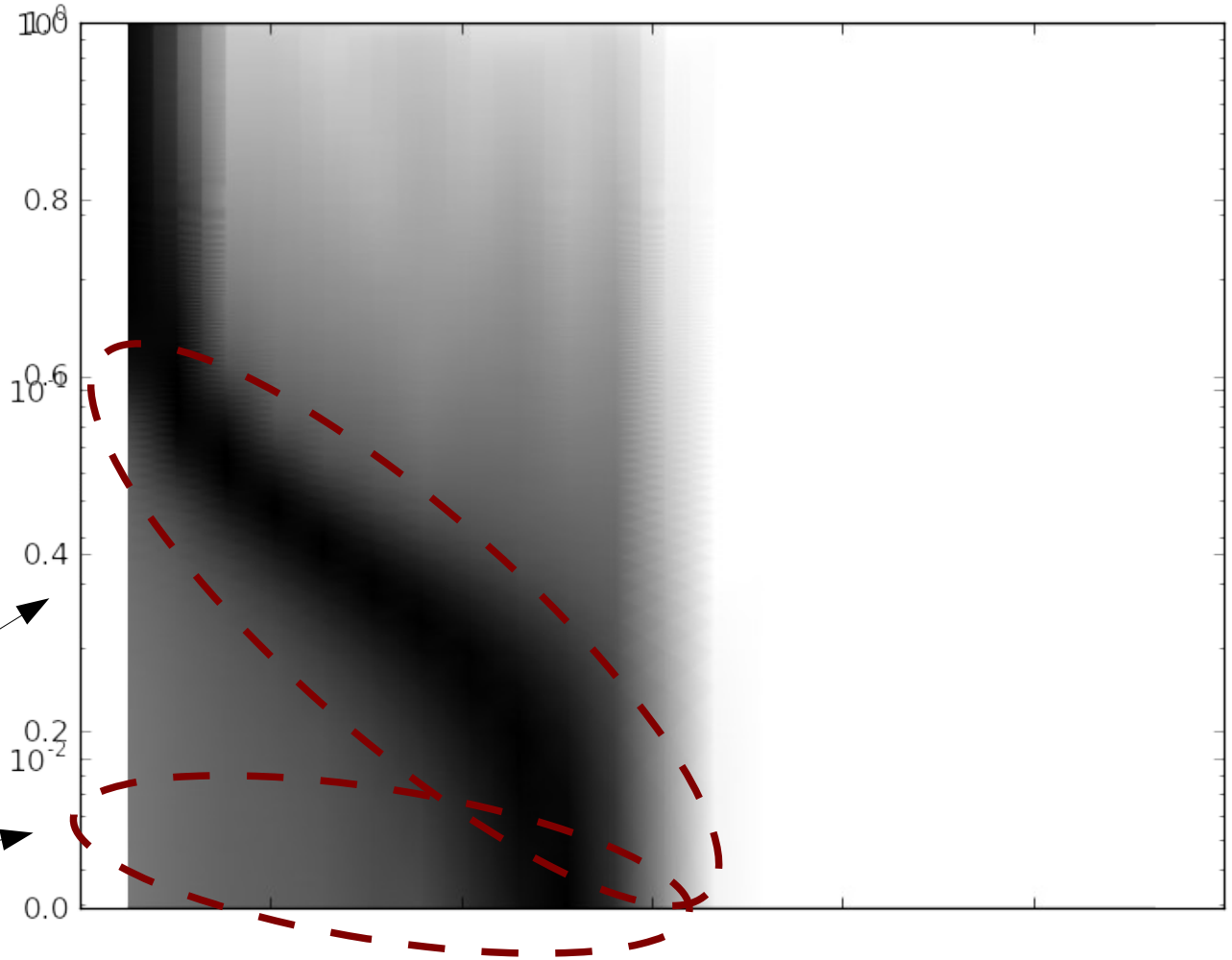
Warped Comb Filter Set

Warped
Impulse
Response

c = .9

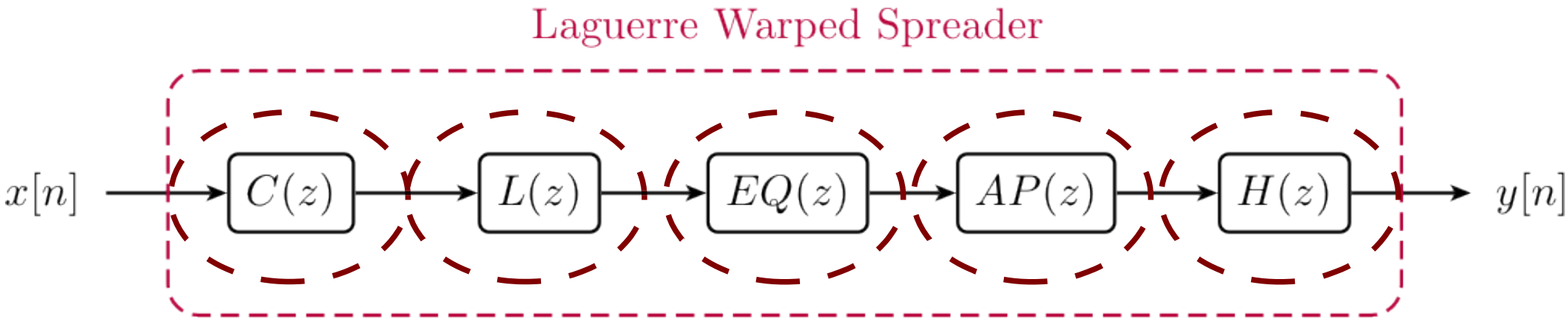
All-pass filter

Time smearing!



Laguerre Warped Spreader

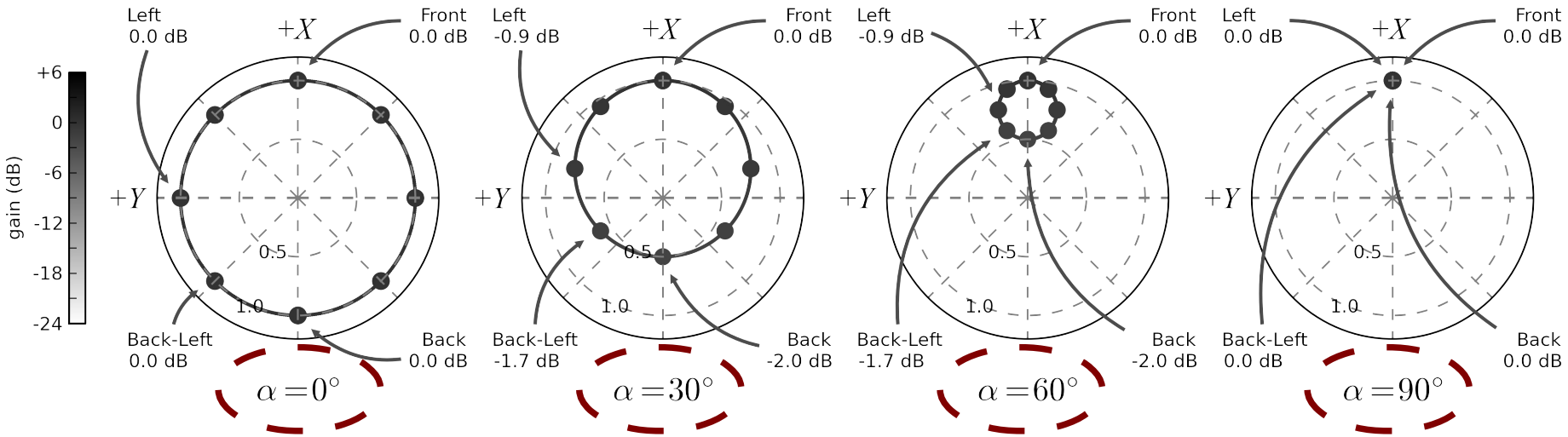
- Components are...
  - Comb filter set
  - Laguerre Transform
  - Equalisation Filter
  - All-pass Filter
  - Hilbert Transform
- … to do...
  - Frequency dependent panning
  - Distribute panning “evenly”
  - Normalise warped response
  - Limit time domain warping
  - Remove “nasty” *j*



Controlling Resulting Soundfield

- Push Transform
  - Allows the resulting soundfield to be shaped in space.

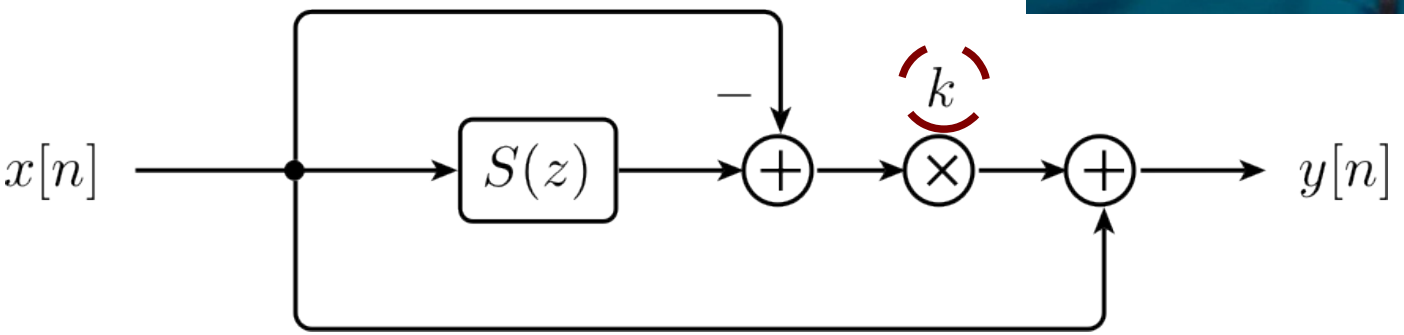
$$\mathbf{U}_{X,\alpha} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ \sqrt{2}\sin|\alpha|\sin\alpha & \cos^2\alpha & 0 & 0 \\ 0 & 0 & \cos^2\alpha & 0 \\ 0 & 0 & 0 & \cos^2\alpha \end{pmatrix}$$



Controlling Resulting Soundfield

- Push...
- Two metaphors:
  - Re-align Tetrahedron
  - Spatial Shelving-Filter

OUTRS tetrahedral microphone array, courtesy Stephen Thornton (www.michaelgerzonphotos.org.uk)



$$k = \sin^2\alpha$$

Animating the Soundfield

- Rotations...
  - Modulate in Time...

Rotate

$$\mathbf{R}_{Z,\theta_t} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_t & -\sin\theta_t & 0 \\ 0 & \sin\theta_t & \cos\theta_t & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Tumble

$$\mathbf{R}_{Y,\phi_t} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi_t & 0 & -\sin\phi_t \\ 0 & 0 & 1 & 0 \\ 0 & \sin\phi_t & 0 & \cos\phi_t \end{pmatrix}$$

$$\mathbf{R}_{X,\phi_t} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos\phi_t & -\sin\phi_t \\ 0 & 0 & \sin\phi_t & \cos\phi_t \end{pmatrix}$$

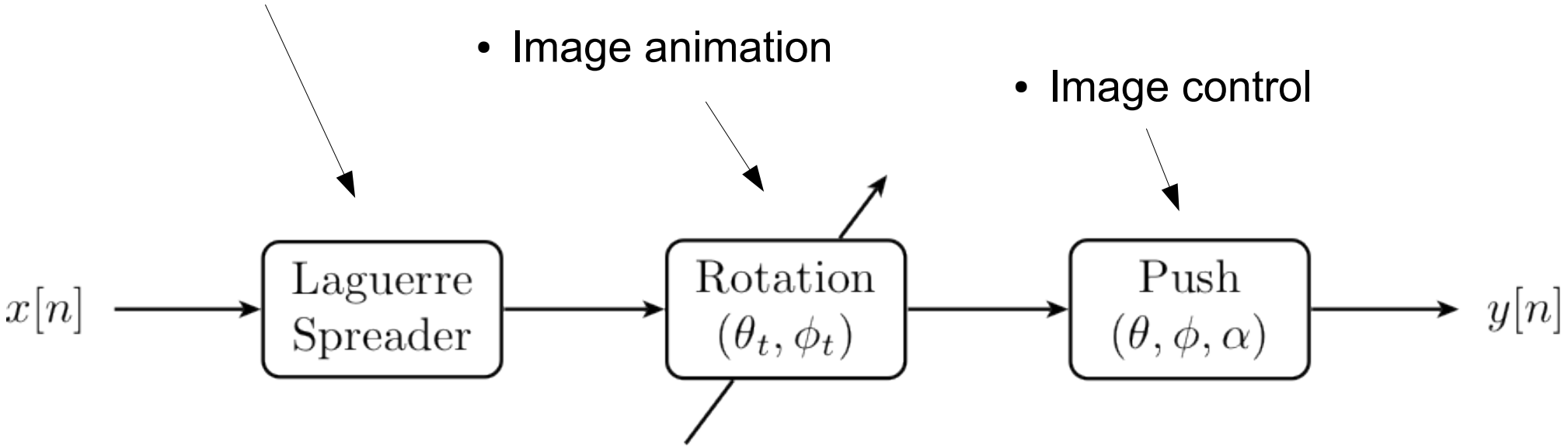
Tilt

Resulting Network

- Final network

Hurrah!

- Image spreading
- Image animation
- Image control



Furthermore...

- Class of effects
- Spatial “Barber pole” phasing / flanging
- “Leslie” effects

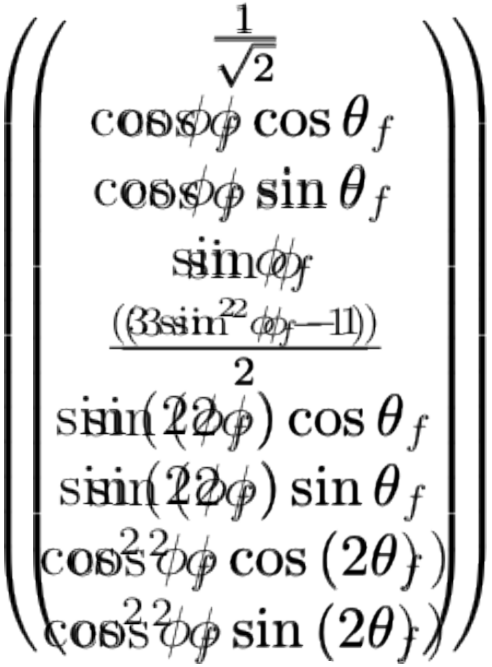
- And...
- Similar tricks with Warped All-pass filters!

Hurrah!!!

Higher Order Ambisonics

- Encoding for 2nd-order Fu-Ma
- Sines and cosines...

Yes, we can do the same trick!



For and against...

Pro

- Technique is relatively “easy” to implement & stable
- Ambisonic transforms can be made frequency dependent
- Various spatial/time domain effects can be created
- HOA, easy!

Con

- Laguerre warping isn't exactly “equal” in log frequency space
- More filter zeros (rotations) = longer filters = more time warping (longer chirps)
- FIR implementation *only, i.e.,* IIRs possible, but problems with chirps
- Will always have some chirping

Summary

- Laguerre Warped Comb Filters
- Versatile tools for ergonomic control of soundfields
- Numerous Ambisonic transforms can be made frequency dependent using this method

Listening & Discussion

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Thanks!!

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