Is My Decoder Ambisonic?

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Ambisonics

- Provides a mathematical encapsulation of auditory localization models
- A single recording can be reproduced on a variety of speaker arrays

But…

- Decoder must be matched to the speaker array geometry and listening conditions

Why test decoders?

- No controlling interest currently
- Current decoders are software written by enthusiasts
  - Many adjustments
  - Scant guidance
  - Users expected to listen and “tune”
  - Difficult to diagnose faults
- Software difficult to validate by inspection

Ambiguity

"The precise definition [of Ambisonics] has been ignored, and the term 'ambisonic' is now applied loosely to any system that makes use of circular or spherical harmonics."

Peter Craven, "The `Hierarchical' Viewpoint,"

Illusions in Sound -- AES 22nd UK Conference, 2007

Consequences

- Quality of information on the web is mixed
- Decoder writers
  - Many defective or improperly used decoders
- Researchers
  - What were they using for their work?
- Listeners
  - Confusing or unpleasant results

Definitions

- Localization models
- Ambisonic criteria

- Used to drive decoder design, *evaluation and validation*

Localization Models

- Two primitive models
  - Velocity localization vector, r_V
    - *ITD -- Blumlein,Clark, et al.*
  - Energy localization vector, r_E
    - *ILD -- Fransen, Mertens, …*
- *Direction* indicates direction of localization perception
- *Magnitudes* indicates quality and stability
  - *In natural hearing, magnitude is 1*
- *Different approach needed for each regime*

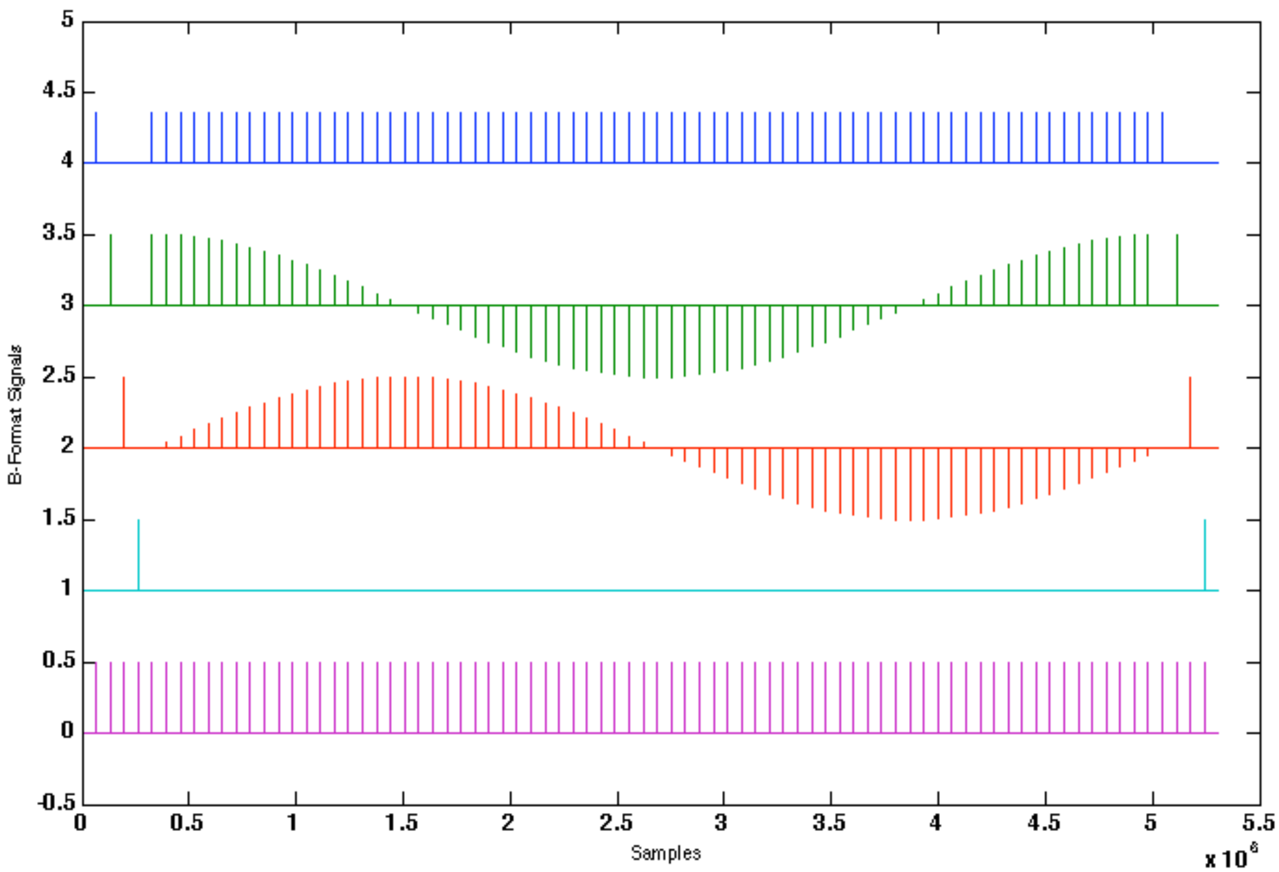
Ambisonic Criteria

- Gerzon's definition
  - Velocity and energy vector directions are the same up to around 4 kHz and are largely unchanged with frequency.
  - At low frequencies, the magnitude of the velocity vector is near 1 for all directions.
  - At mid/high frequencies the energy vector is maximized over as many directions as possible.
- Necessary (if perhaps not sufficient) for good surround sound reproduction
- Confirmed by listening tests

Test Procedure

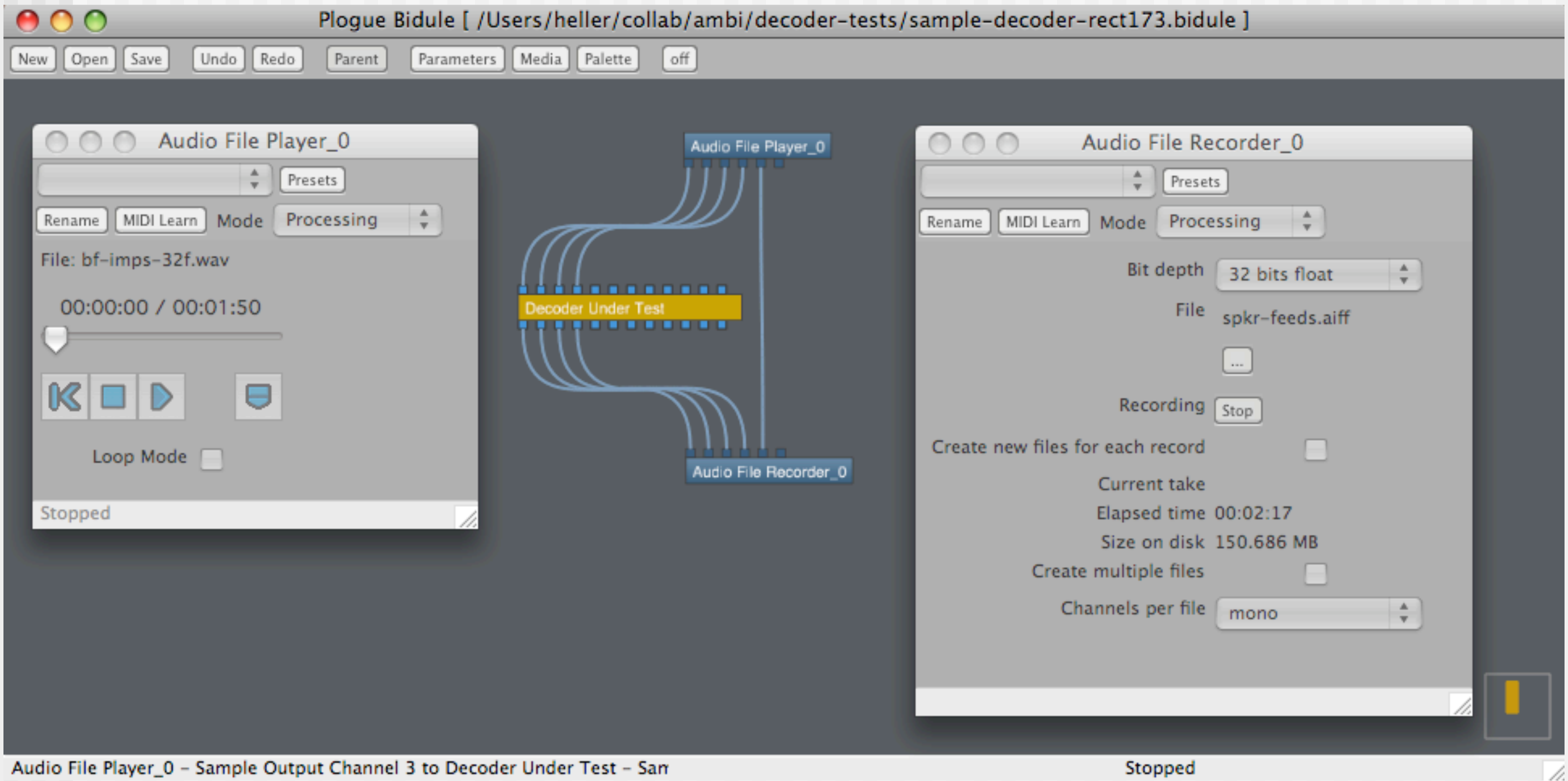
- Measure Impulse Response from a variety of directions
- Evaluate those against the Ambisonic criteria
- Current paper examines
  - A single speaker array ($\sqrt{3}$: 1 rectangle)
  - Four decoders
- Matlab code to generate test signals and analyze results

Test signal



B-Format Signals
Samples
x 10^6
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5

Typical Test Harness



Speaker Array Geometry

- Regular polygons and polyhedra
  - Often difficult to fit into real rooms
- Irregular, but diametric opposite pairs
  - Rectangles, bi- and tri-rectangles
- General irregular arrays
  - ITU 5.1, hemispheres

- *Assumption that all arrays can be treated as regular polygonal is the most common error*

Components of a decoder

- Decoder matrix matched to speaker array geometry
- Phase-matched dual-band processing
- Near-field compensation

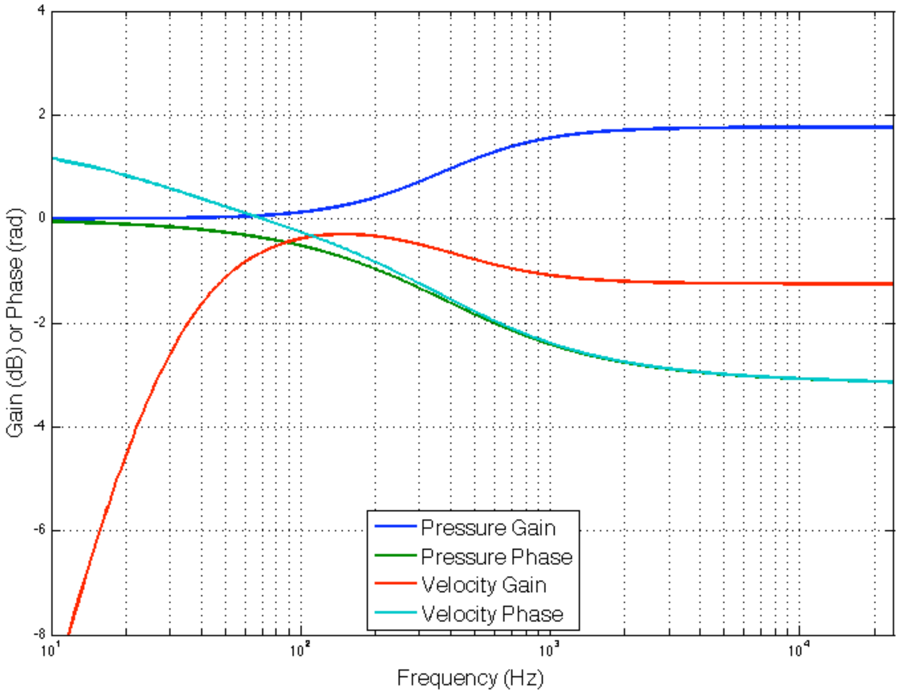
- Cookbook design procedures for all three components in Appendix.

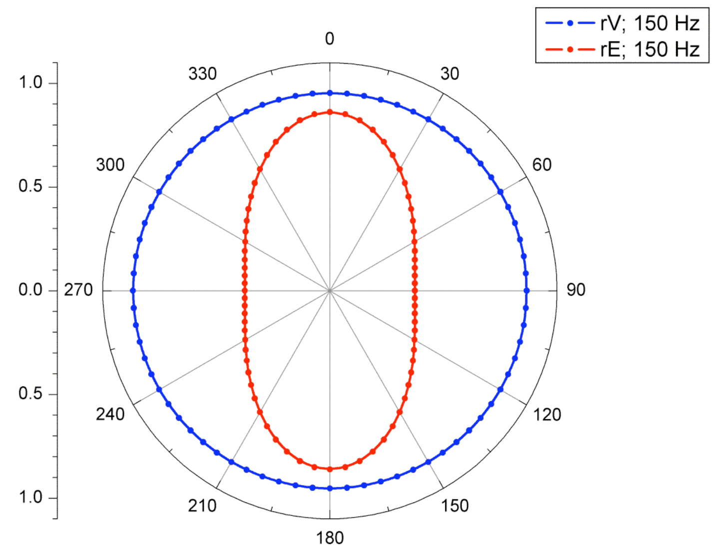
- *Lack of dual-band processing is another common problem*
  - *Poor localization or comb filter artifacts*

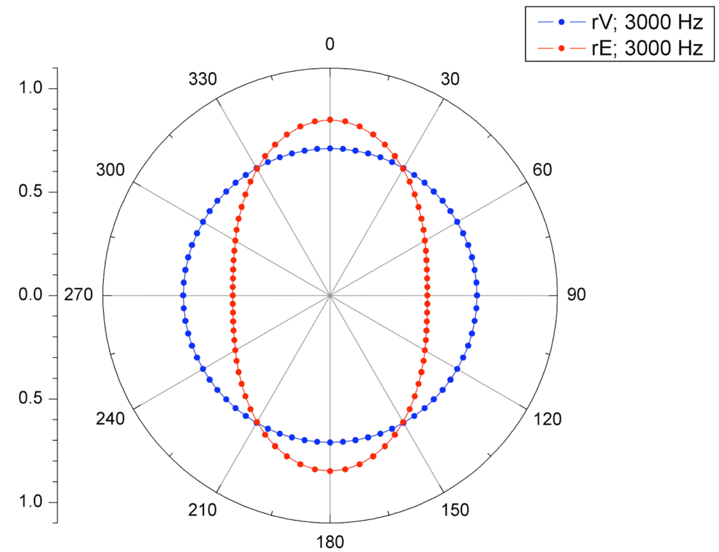
Types of Decoders

- Matrix and other parameters entered directly
  - Adriaensen's *AmbDec*
- Presets for various array geometries
  - Csound, CMT, …
- Virtual Microphones
  - Many VST and AU plugins

AmbDec

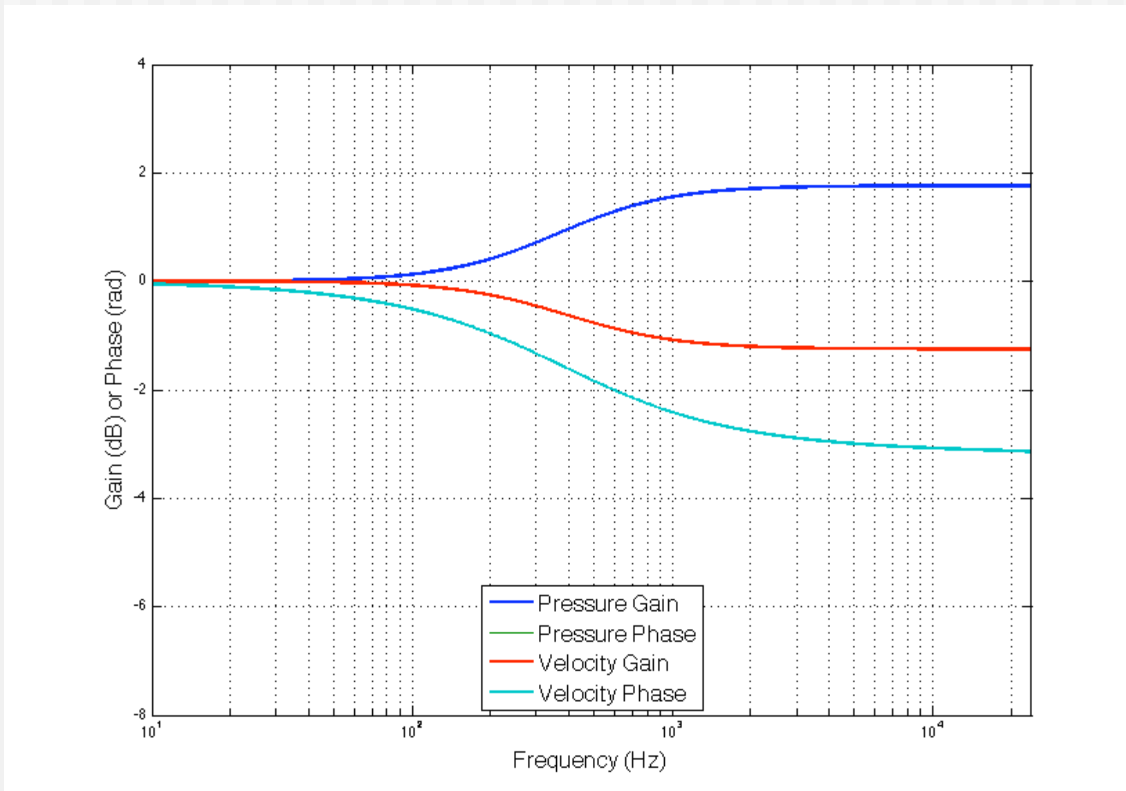


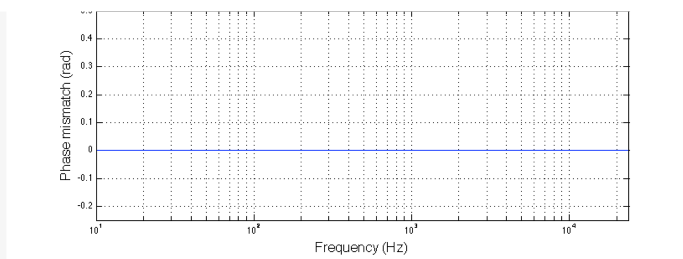




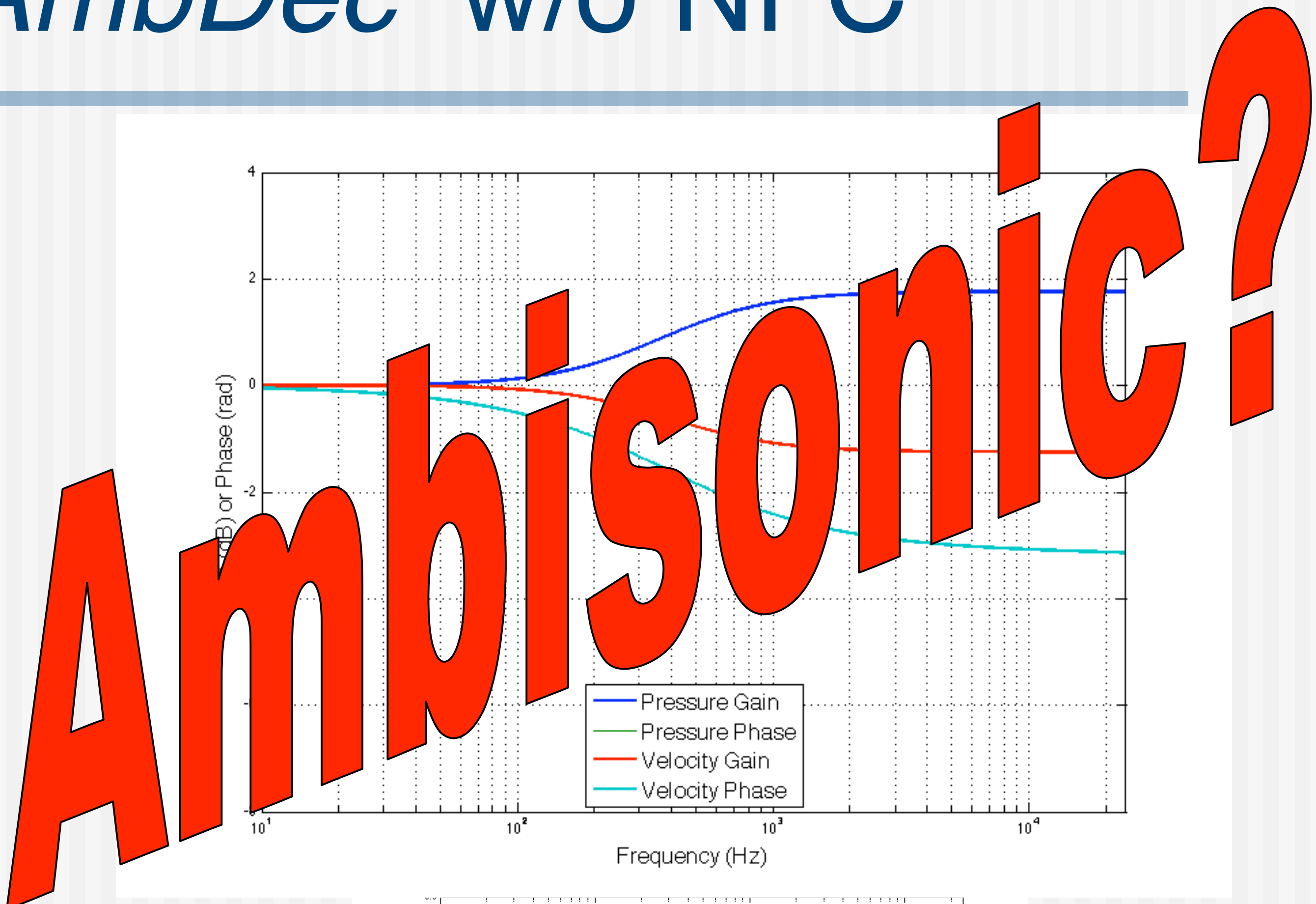
Decoder matrix and parameters derived by procedures in appendix

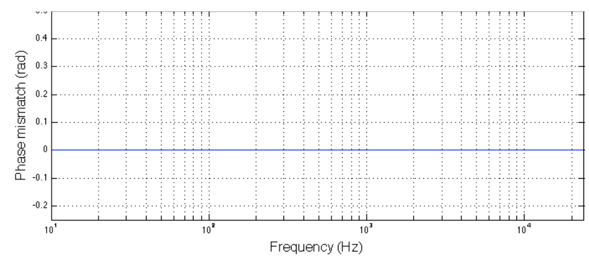
AmbDec w/o NFC



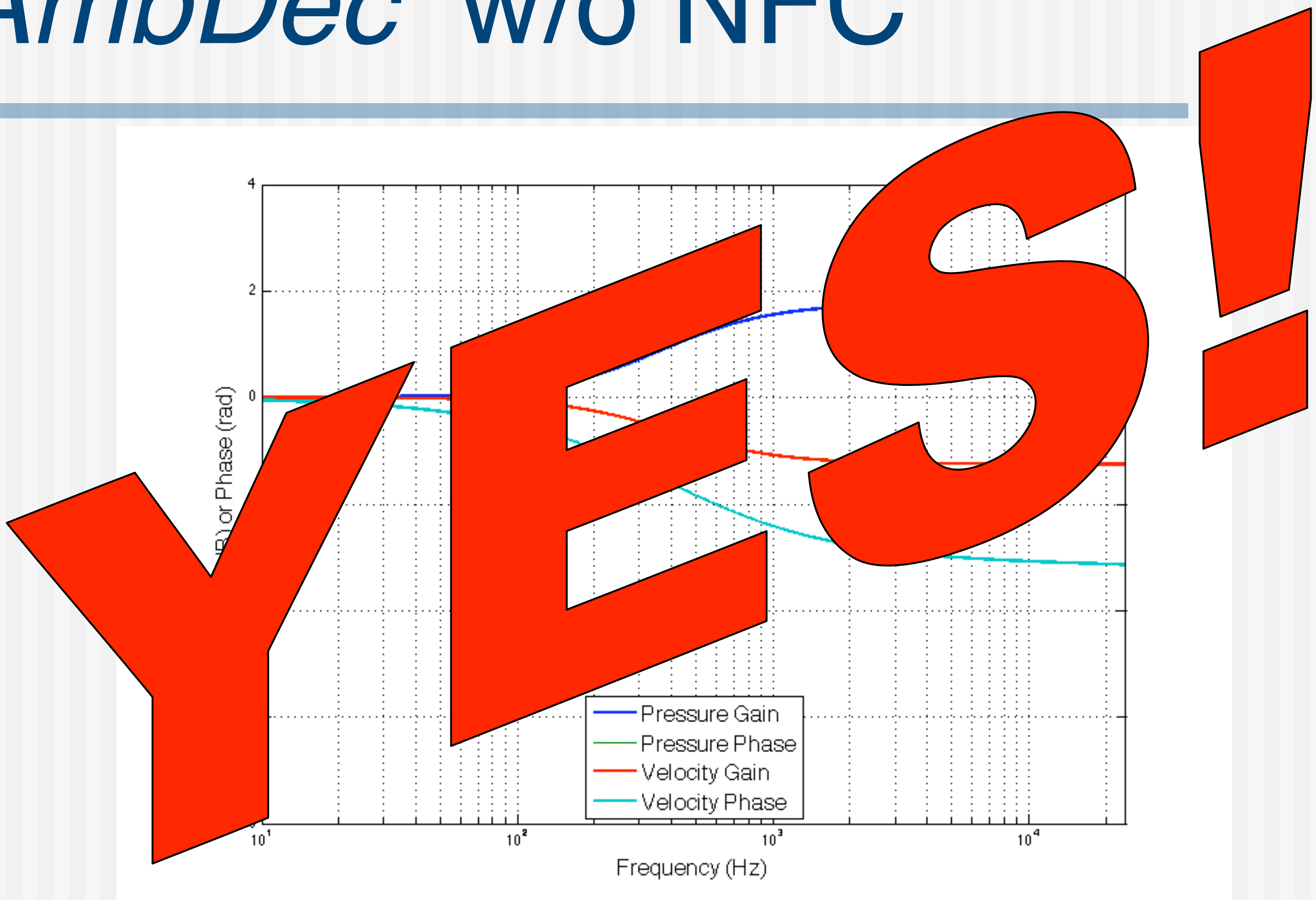


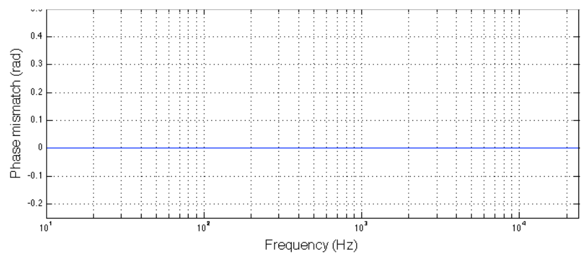
AmbDec w/o NFC





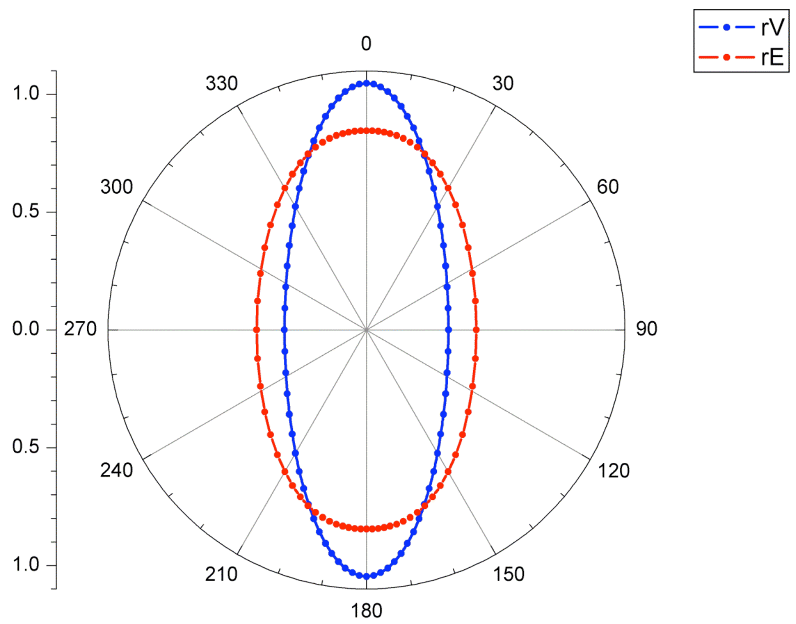
AmbDec w/o NFC



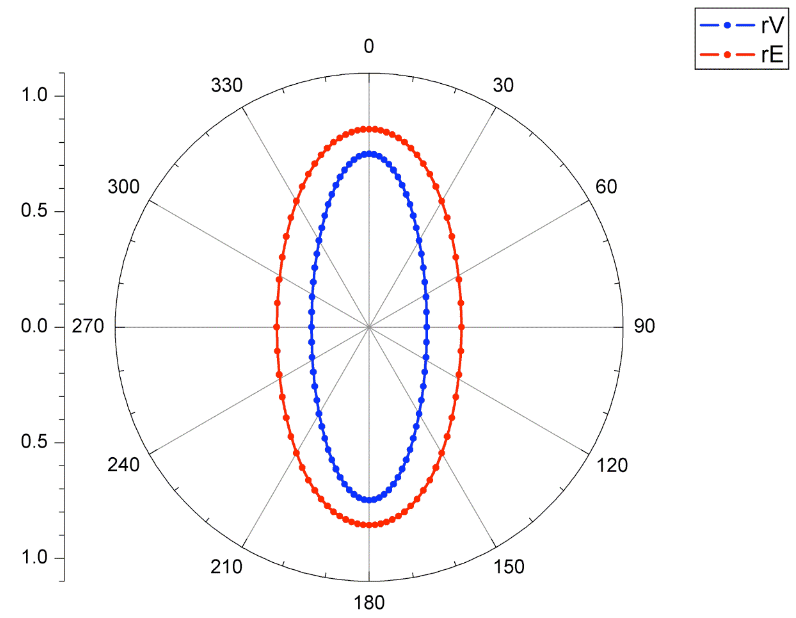


VST Plugin (virtual mic type)

150 Hz



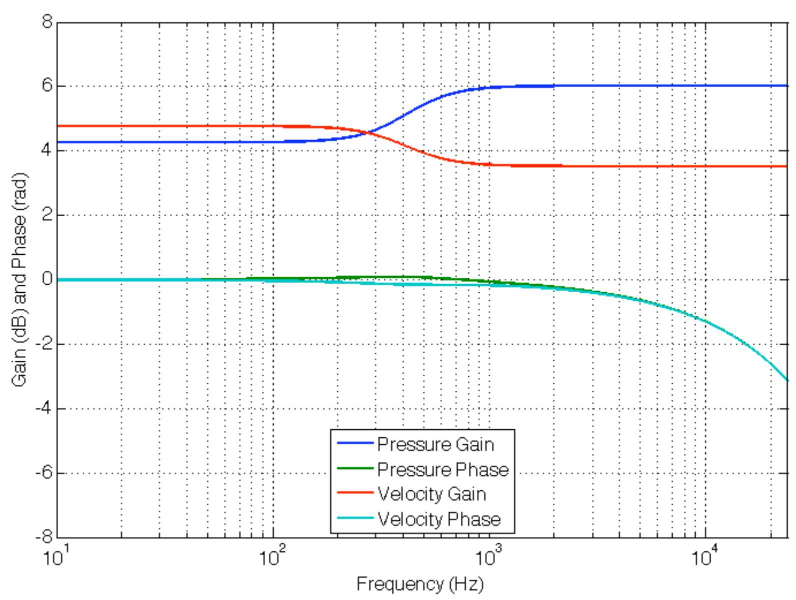
3 kHz



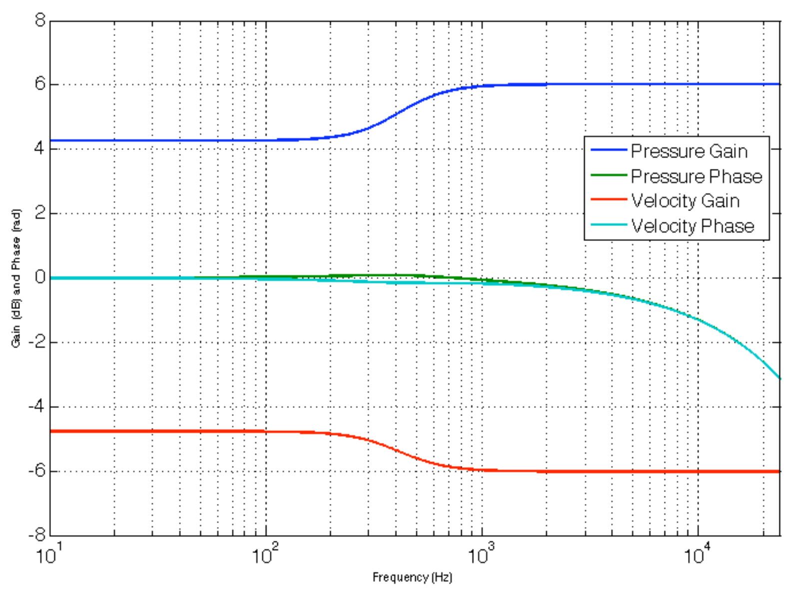
Virtual mics pointed at loudspeakers per directions. Other parameters left at default settings.

VST Plugin

0 degrees



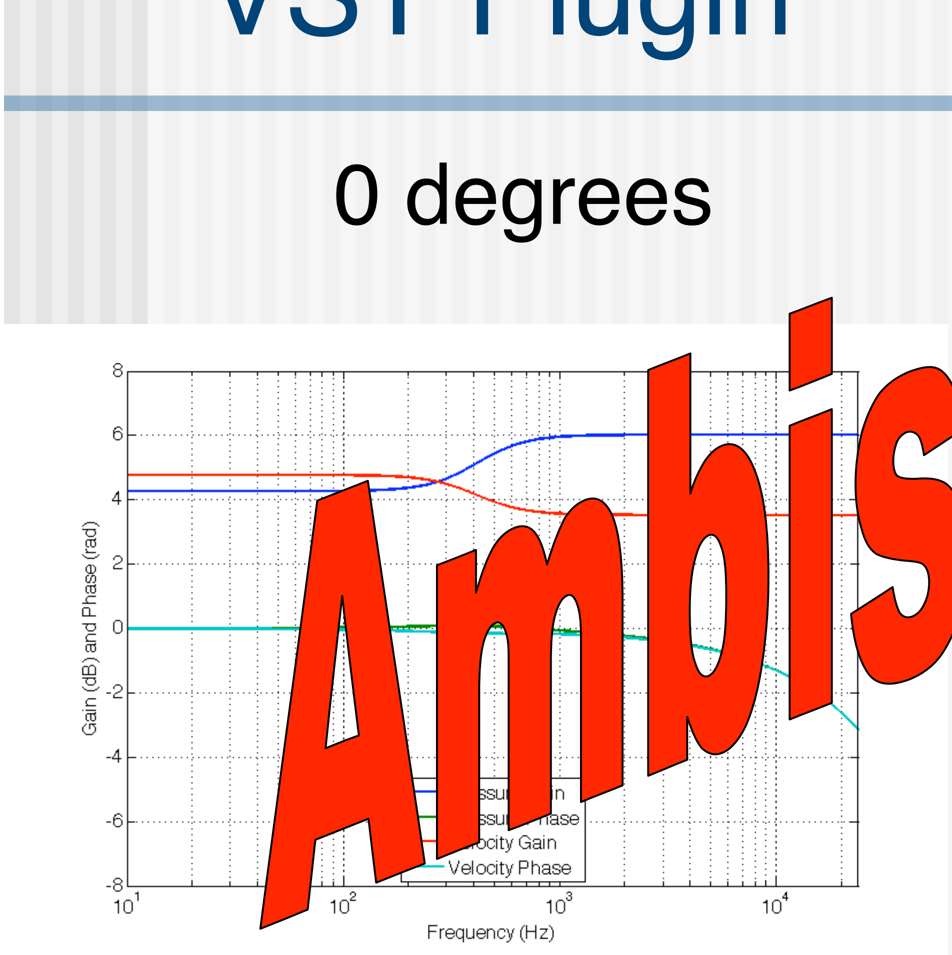
90 degrees

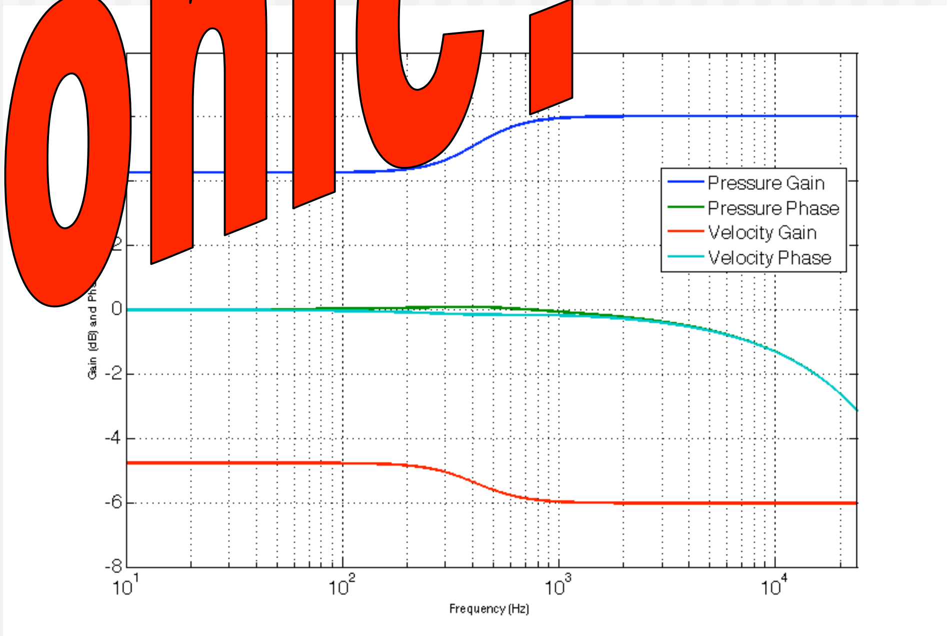


VST Plugin

0 degrees

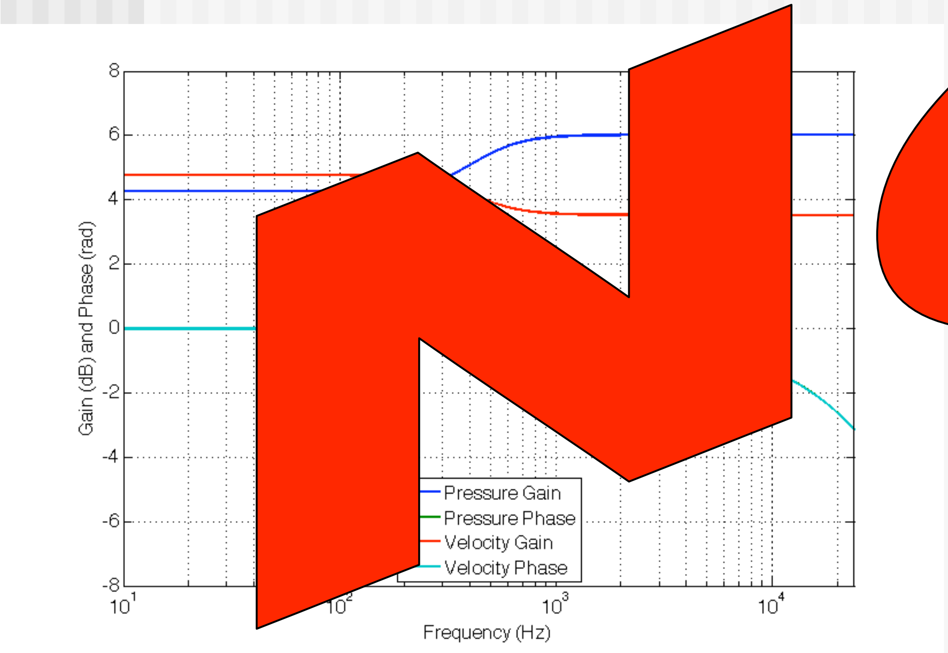
90 degrees



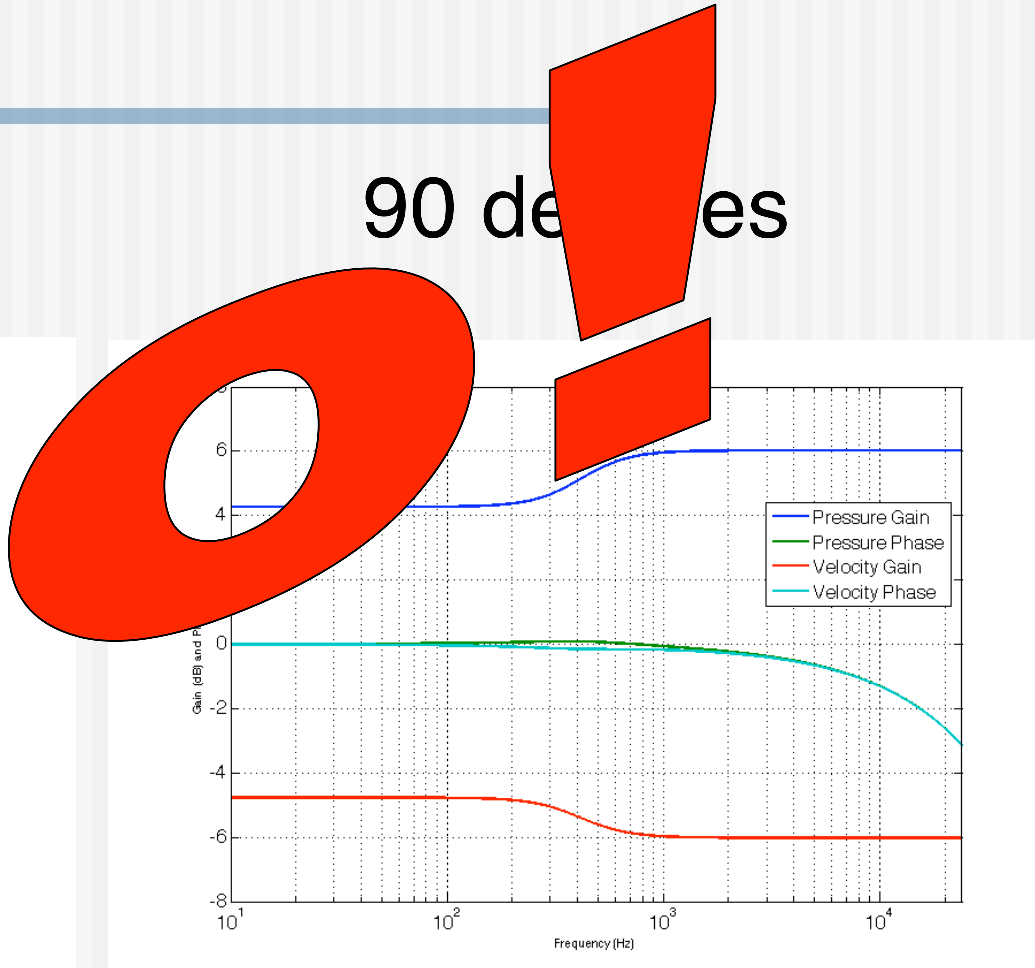


VST Plugin

0 degrees

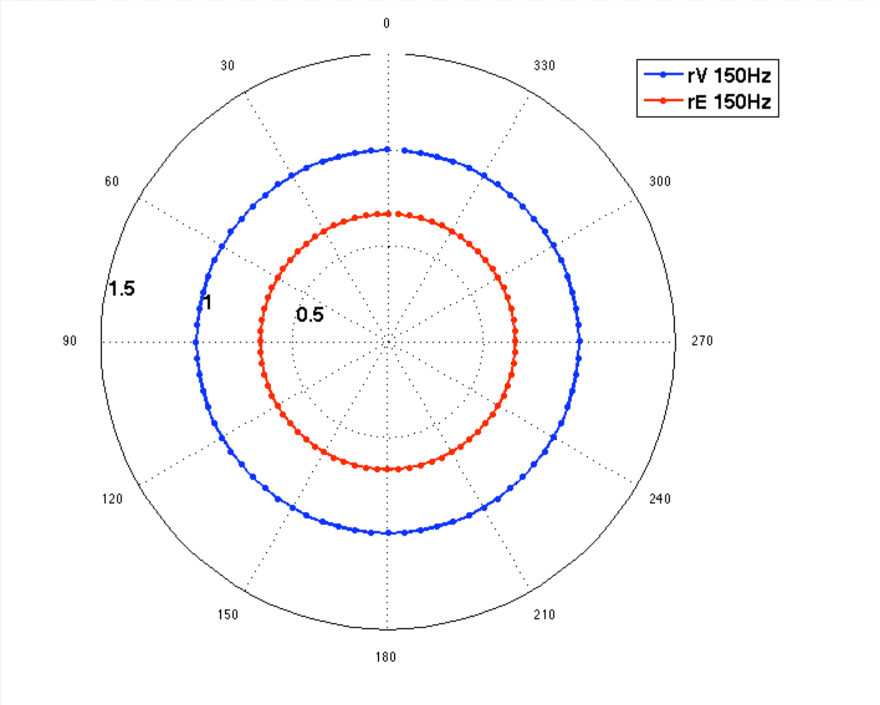


90 degrees

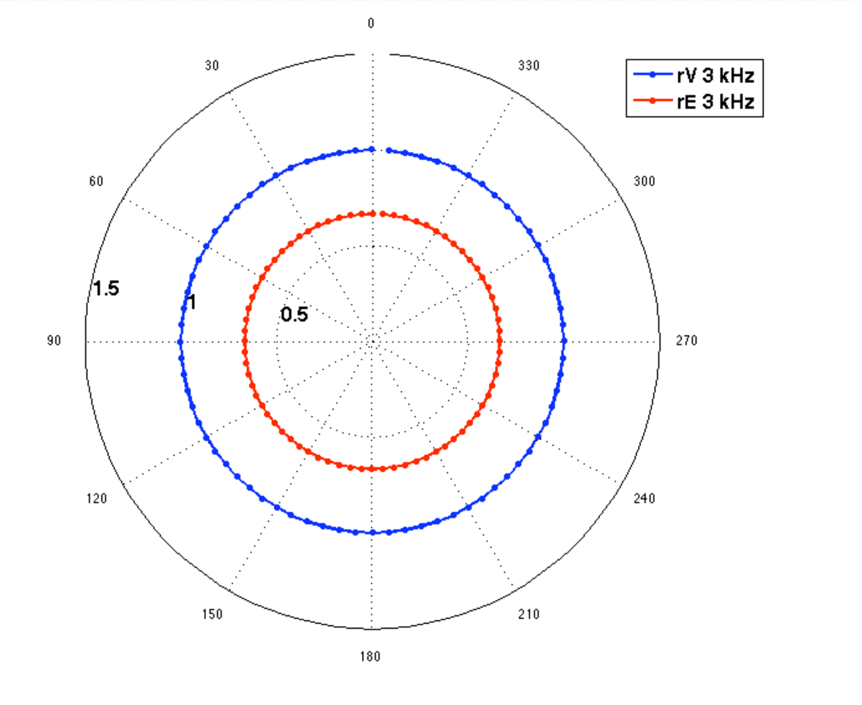


Csound “bformdec” opcode

150 Hz

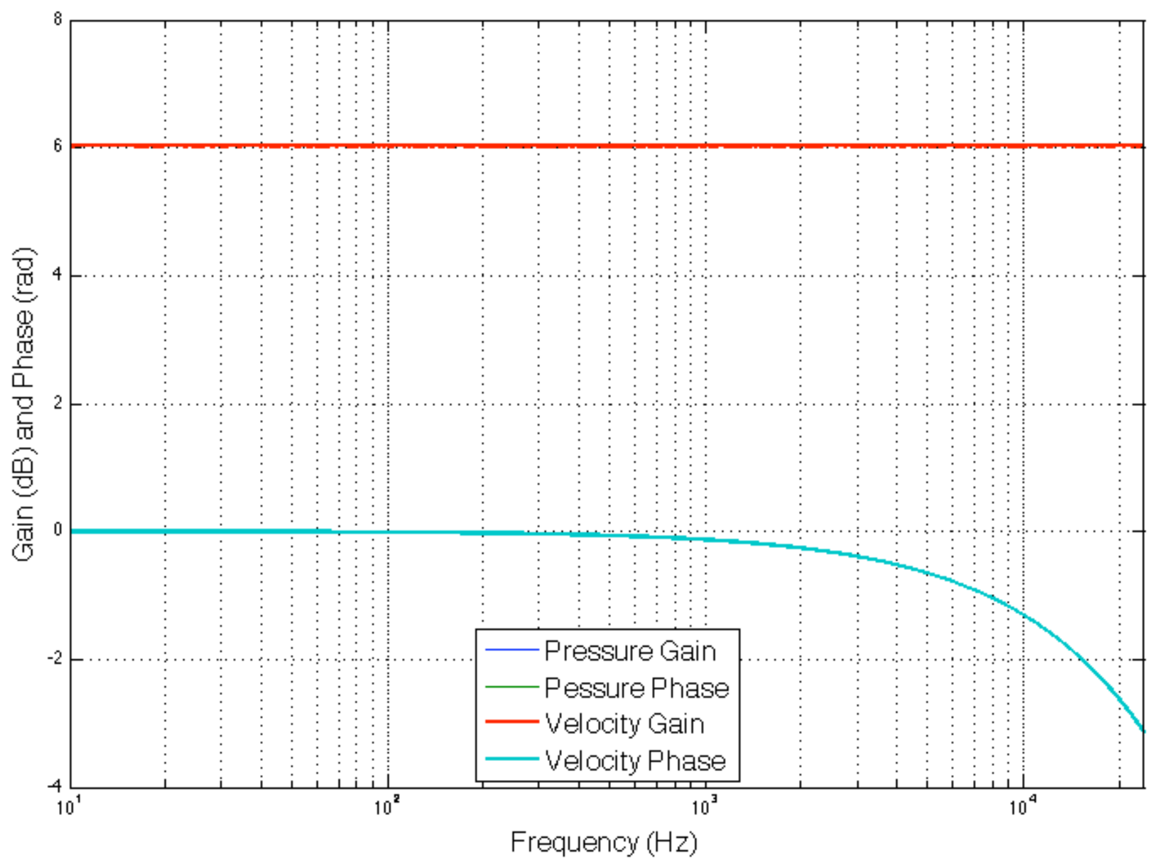


3 kHz



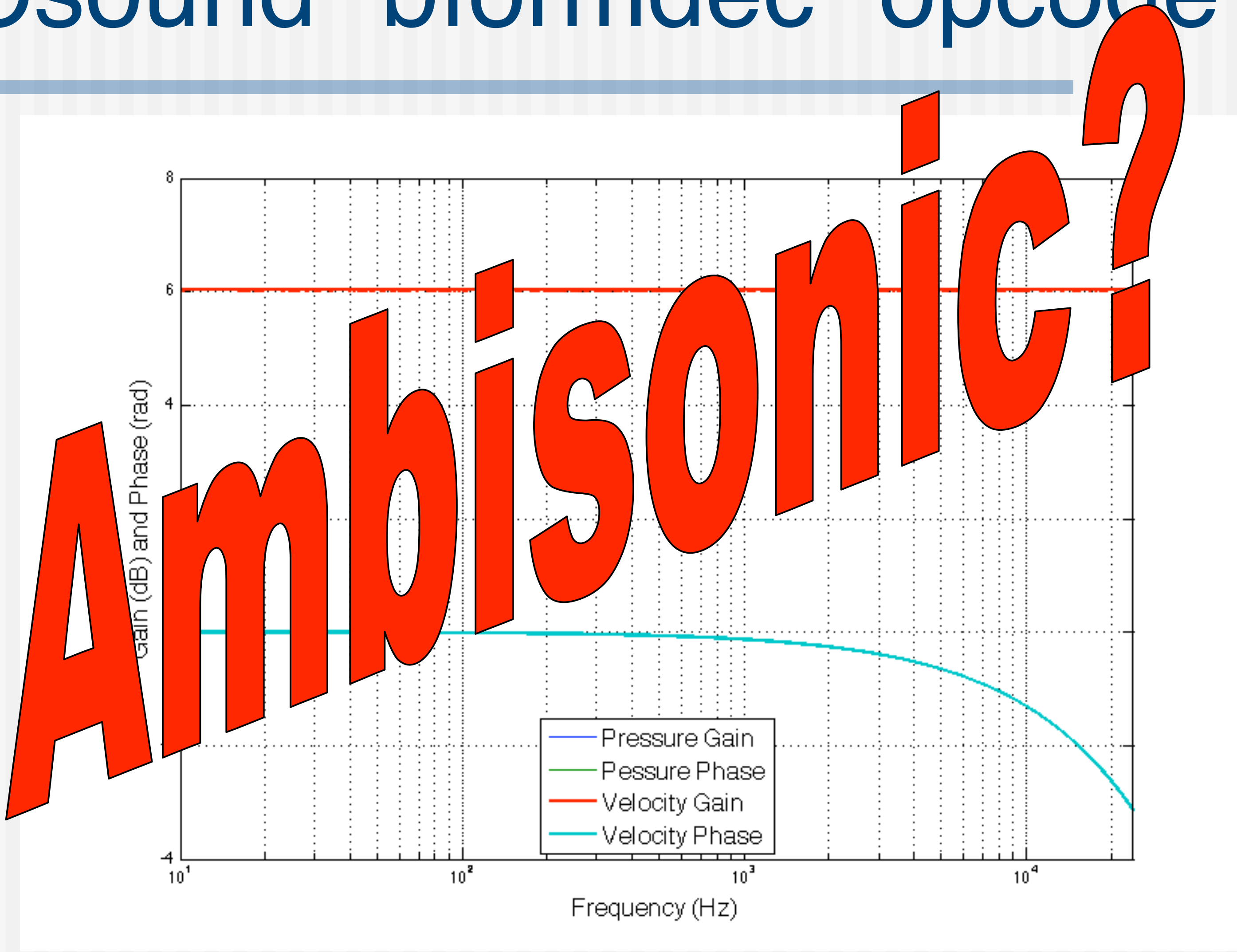
Tested square decoder

Csound "bformdec" opcode



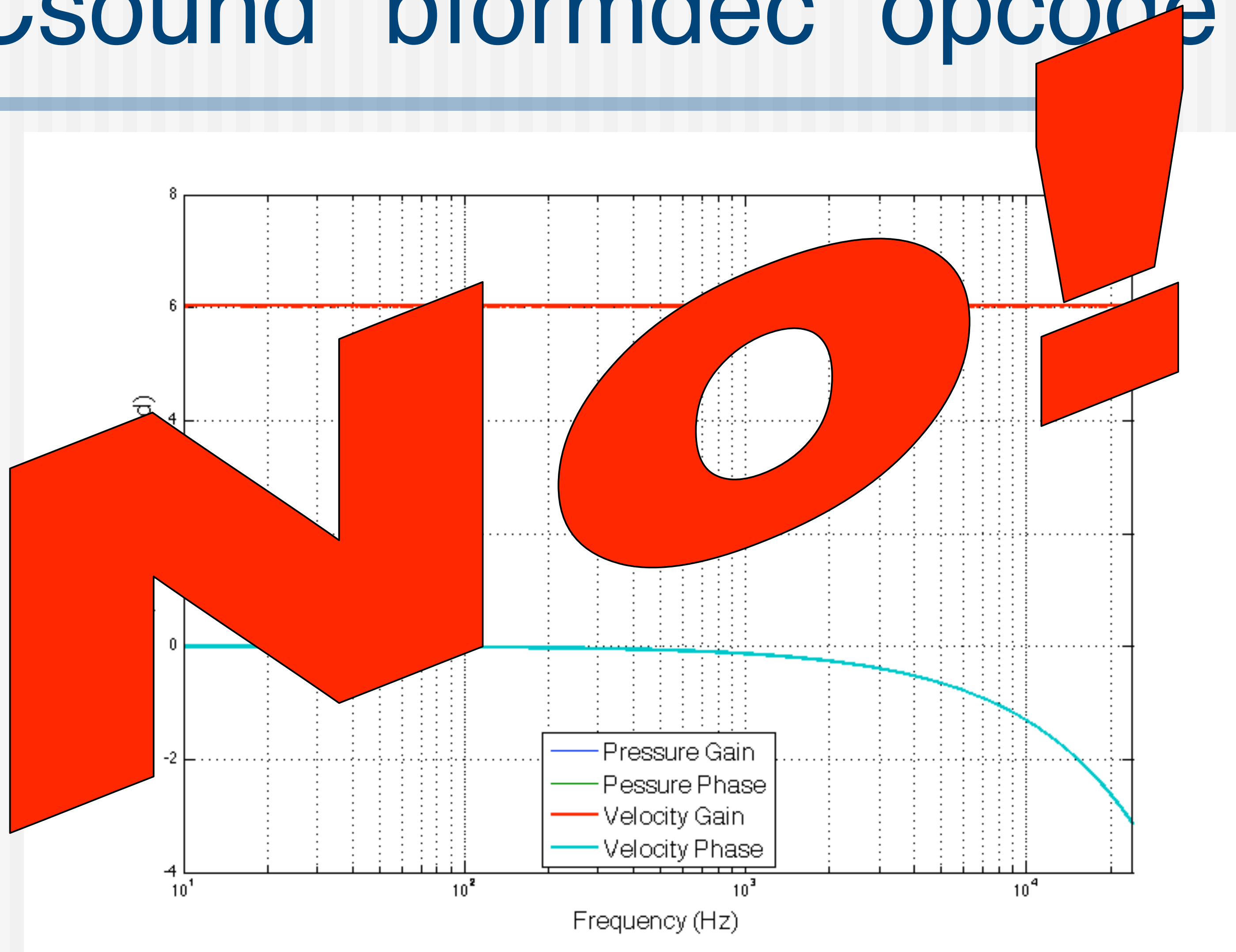
Tested square decoder

Csound “bformdec” opcode



Tested square decoder

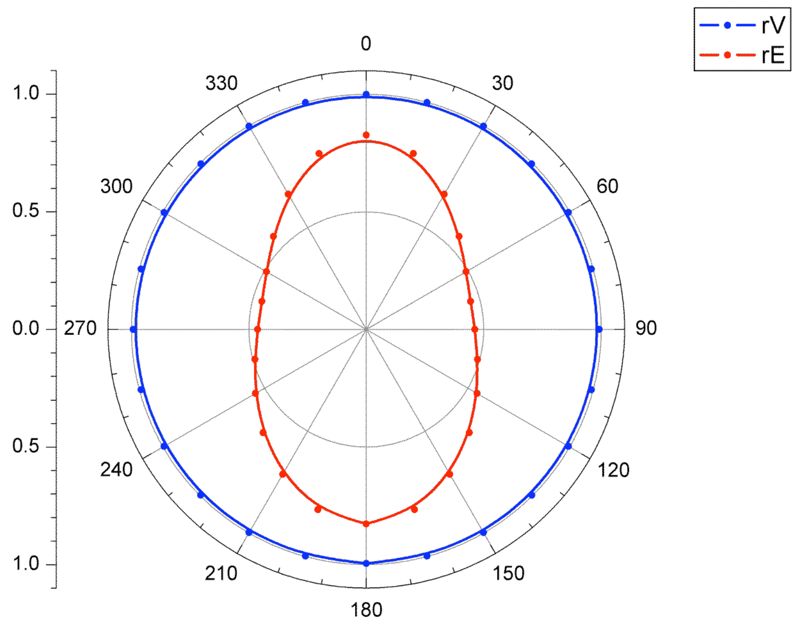
Csound “bformdec” opcode



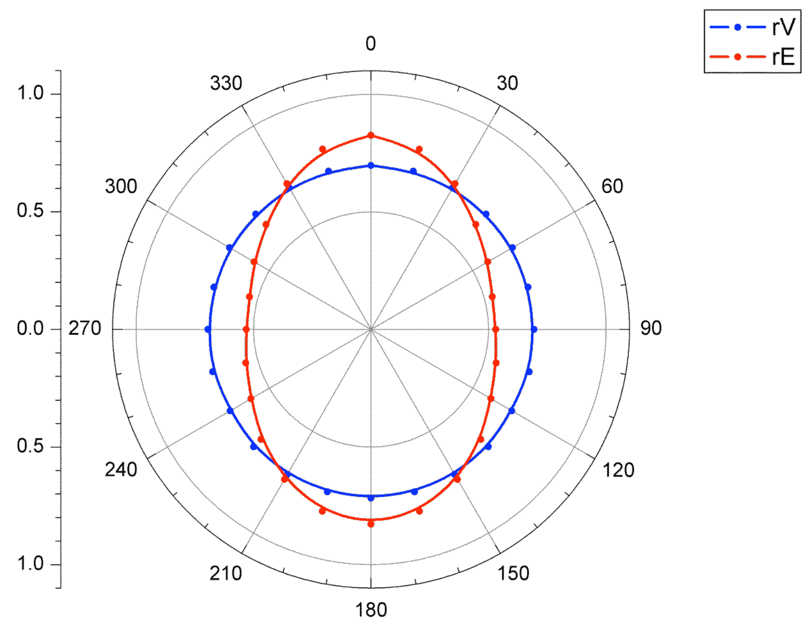
Tested square decoder

Minim AD-10

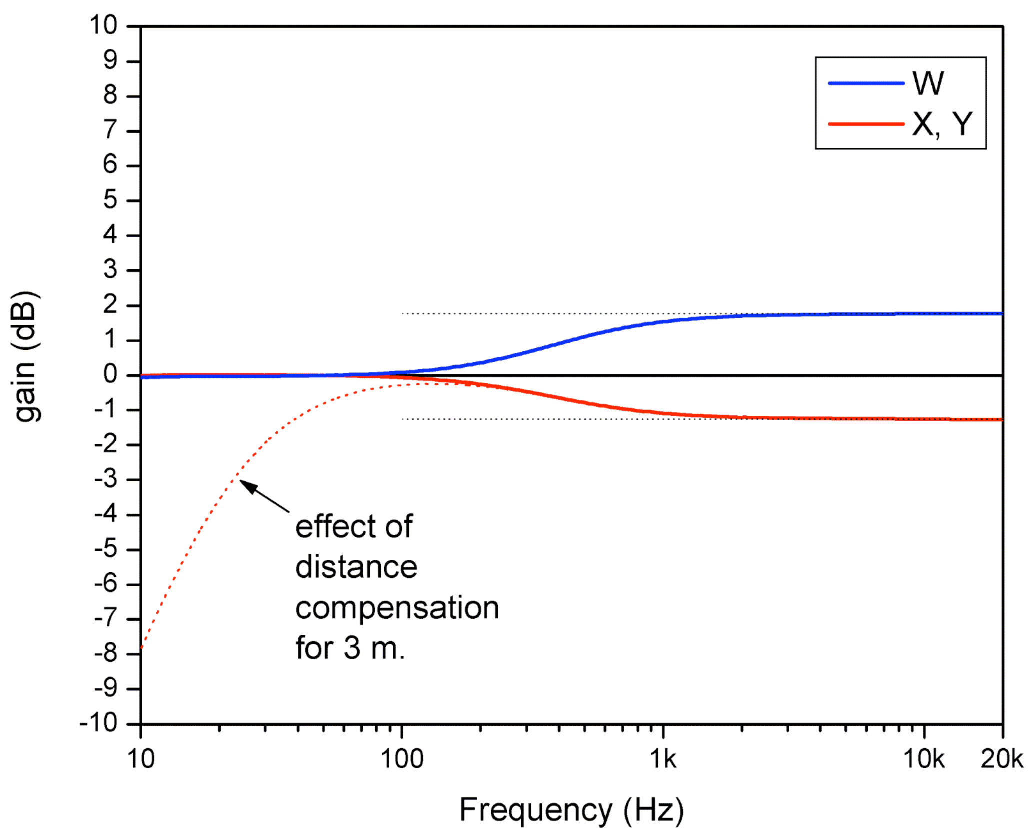
150 Hz



3 kHz

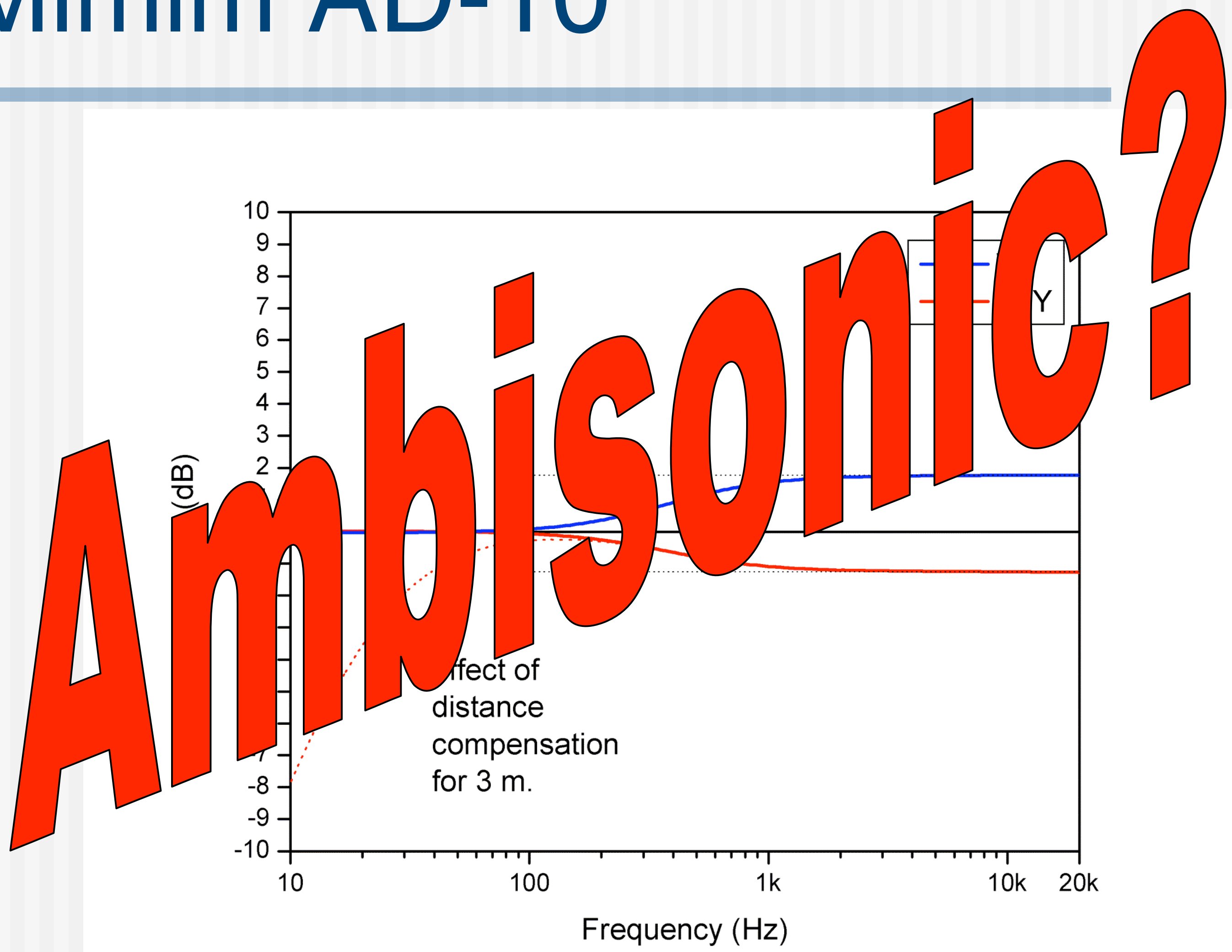


Mimim AD-10



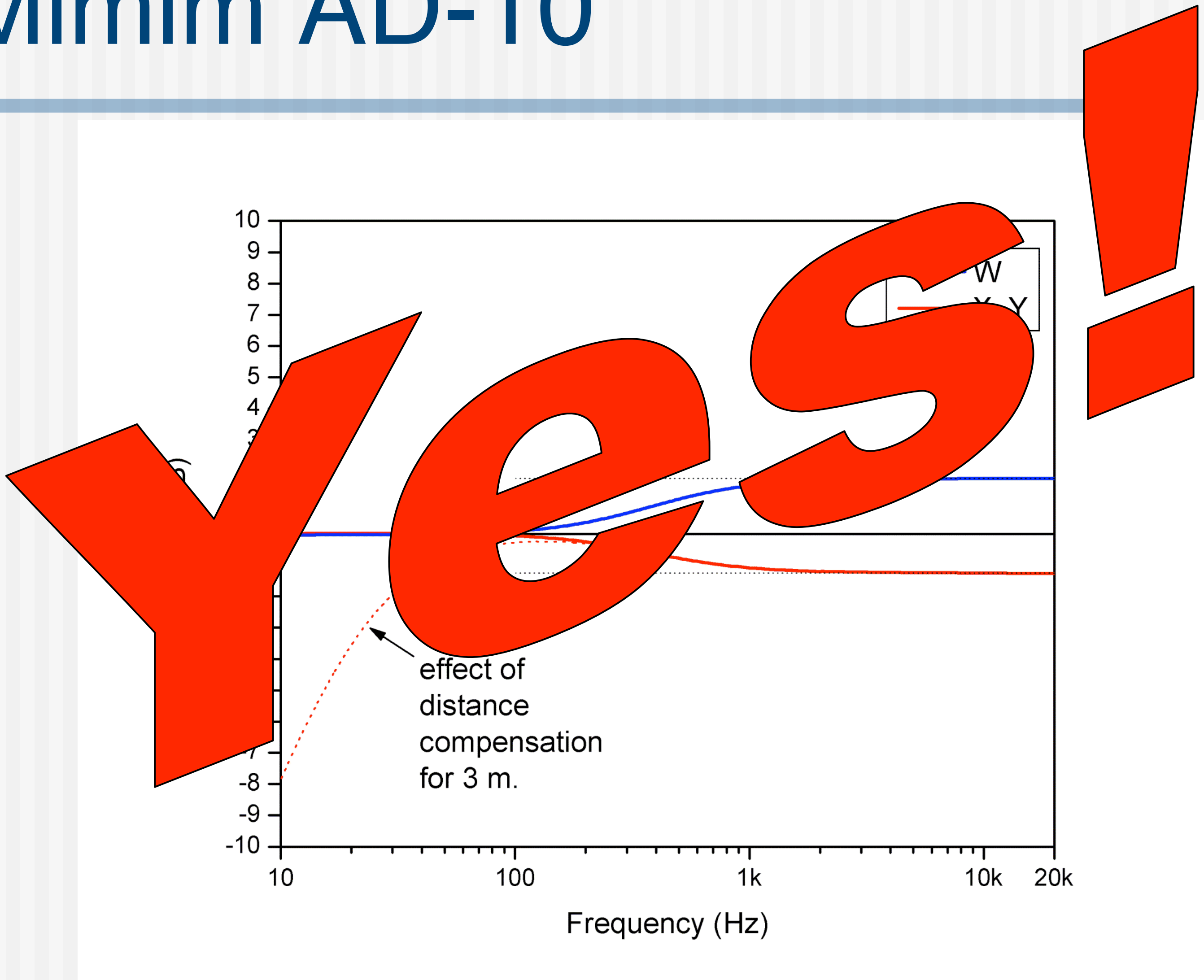
W
X, Y
effect of distance compensation for 3 m.
gain (dB)
Frequency (Hz)
10
100
1k
10k
20k

Mimim AD-10



Ambisonic?
10
9
8
7
6
5
4
3
2
(dB)
Y
-8
-9
-10
10
100
1k
10k
20k
Frequency (Hz)
distance
compensation
for 3 m.

Mimim AD-10



Yes!
10
9
8
7
6
5
4
-8
-9
-10
10
100
1k
10k
20k
Frequency (Hz)
W
effect of
distance
compensation
for 3 m.

Informal Listening Tests

- Same material as earlier tests
- Ambdec
  - Good localization and envelopment
  - No audible artifacts
- Decoder 2 (VST Plugin)
  - Front and rear localization only
- Csound “bformdec” (simulated)
  - Comb filtering and in-head localization artifacts

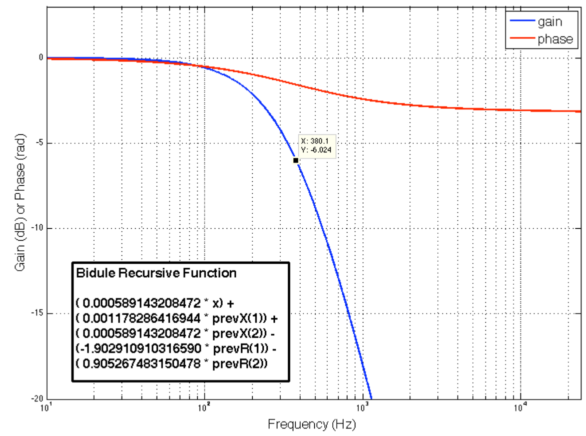
Decoder Design

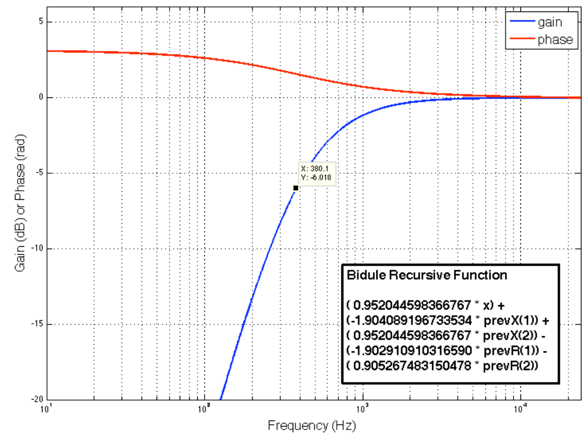
- Decoder matrix derived by generalized inversion
  - Pick a basis set of spherical harmonics
  - "project" speaker locations onto basis set
  - Goal - reproduce basis set (exact solution)
    - Many solutions, want minimum radiated power
  - Use Moore-Penrose Pseudo-Inversion
    - Singular Value Decomposition

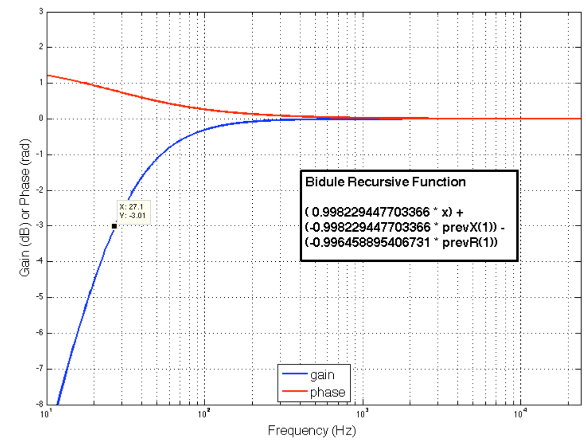
      $A = U \Sigma V^* \;\; \text{->} \;\; A^\dagger = V \Sigma^\dagger U^*$
  - pinv() in Matlab and Octave
  - Equivalent to Least-Squares solution
    - Minimum radiated power, highest average r_E

Decoder Design

- Phase-matched bandsplitting and NFC filters
- Cookbook procedures for design
- Sample implementation using Bidule recursive function block







Is My Encoder Ambisonic?

- Ambisonics can encode
  - Distance, diffuse fields, standing wave
- In fact, a properly aligned Ambisonic microphone must do this.
  - This is the proximity effect in all directional microphones
- Hence, Ambisonic panner/encoder should have these as well.
- See paper for details.

Conclusions

- Most decoders do not meet Ambisonic criteria
  - Incorrect coefficients for irregular arrays
  - Lack of dual-band decoding
  - Lack of near-field compensation
- Results in
  - Poor localization
  - Uncomfortable effects
- Good B-format material is now available
- Next, we need easy-to-use playback software

Further info

- Read the paper
- Web site URL
  - http://www.ai.sri.com/ajh/ambisonics
  - http://www.ambisonia.com
- Demonstration tonight, 6 - 9PM
  - Bubble, 73 Langton St, SF (3 blocks from Moscone)
  - 24-speaker hemispherical array
  - Decoder derived via techniques described here