Why Higher Sampling Rates Are Better… And Worse

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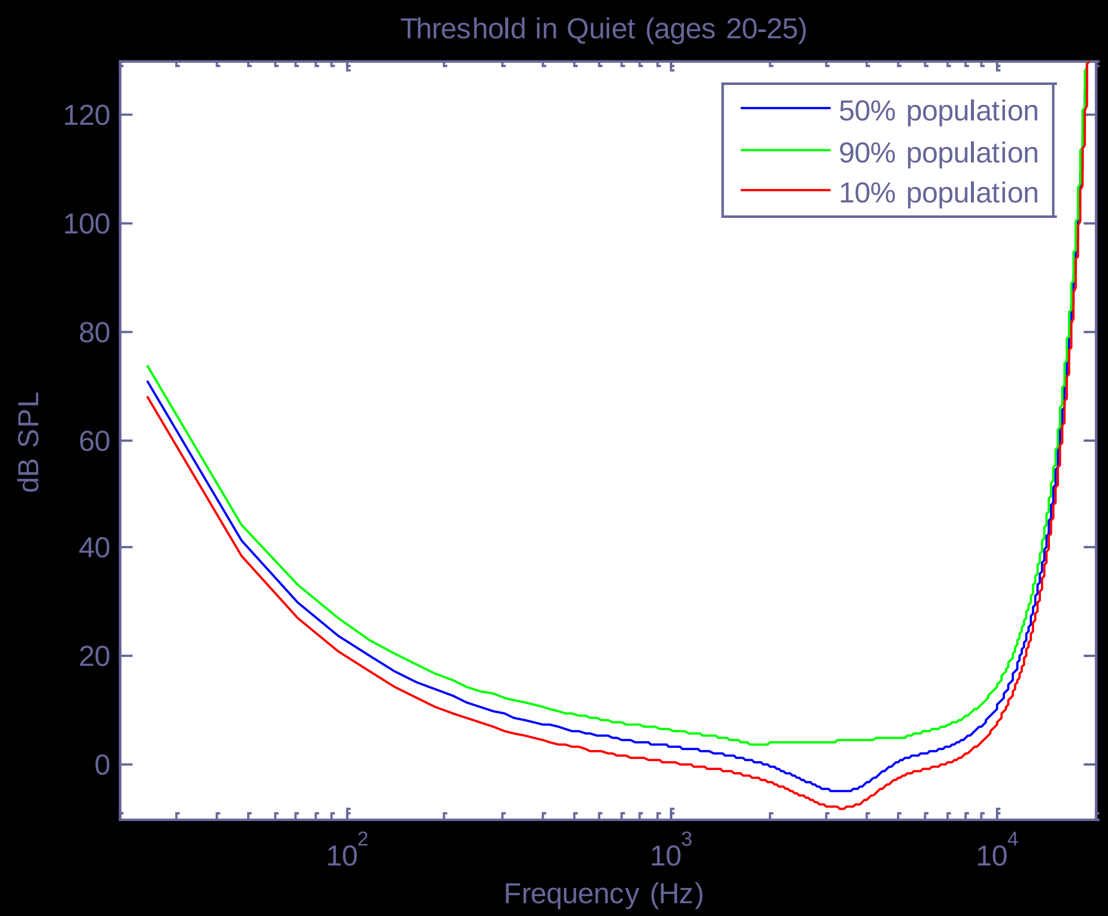
Today's Topics

- Limits of hearing
- Filters, Phase, and Group Delay
- Mixing & Monitoring
- Stereo Imaging
- Jitter & other effects of too much caffeine

Threshold of Hearing



Adapted from Zwicker & Fastl

So we can’t hear high freqs… How about “sensing” them?

- Oohashi, et al. found that brain electrical activity and blood flow changed significantly when frequencies above 20kHz were present.
- Interesting note- it took about 20sec for the brain to respond to high frequencies.
- To my knowledge, this research has not yet been duplicated.

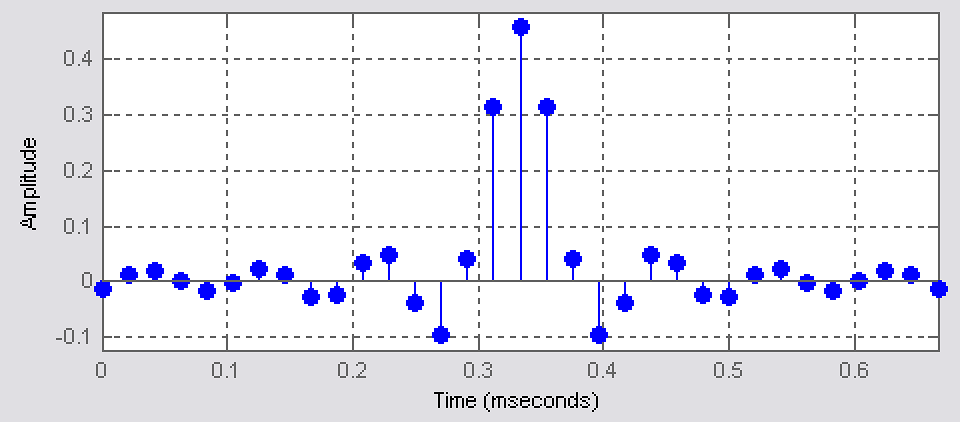
Filters, Phase, and Group Delay

- Sidenote on temporal “smearing” / Pre-Echo
  - Frequency -vs- Time
- Phase / Group delay
  - Linear Phase / Constant Group Delay
  - Nonlinear / Frequency Dependent Group Delay

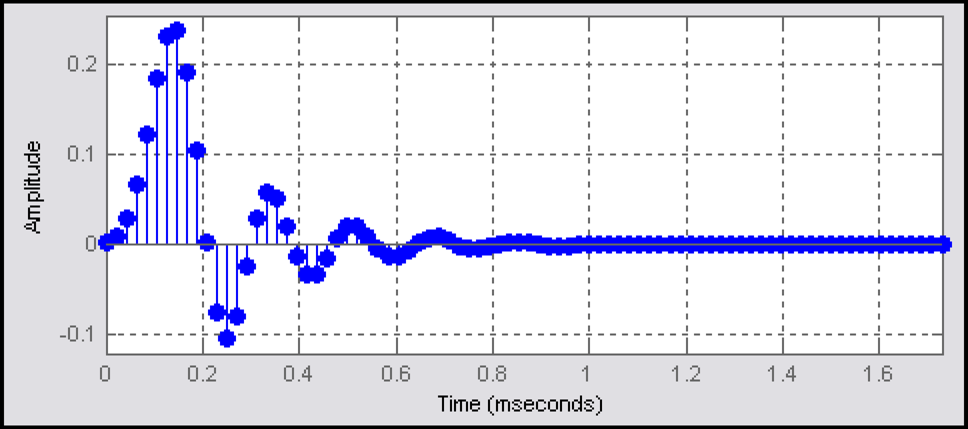
“A New Perspective on Decimation and Interpolation Filters”
by Steve Green (Cirrus Logic)
http://www.cirrus.com/en/pubs/whitePaper/DS668WP1.pdf

Pre-Echo

- Typical [linear phase] FIR filter response:

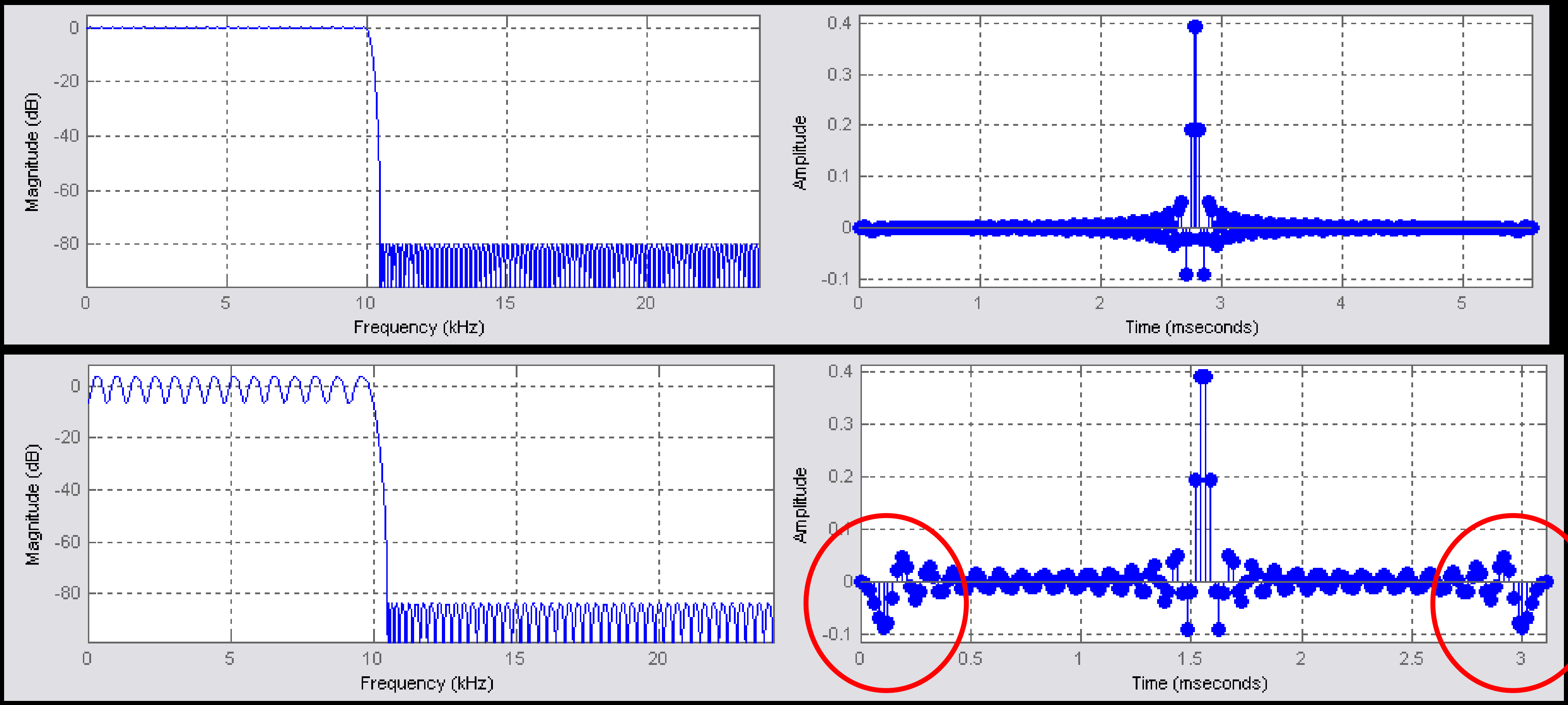


- Typical IIR filter response:

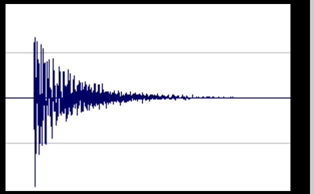


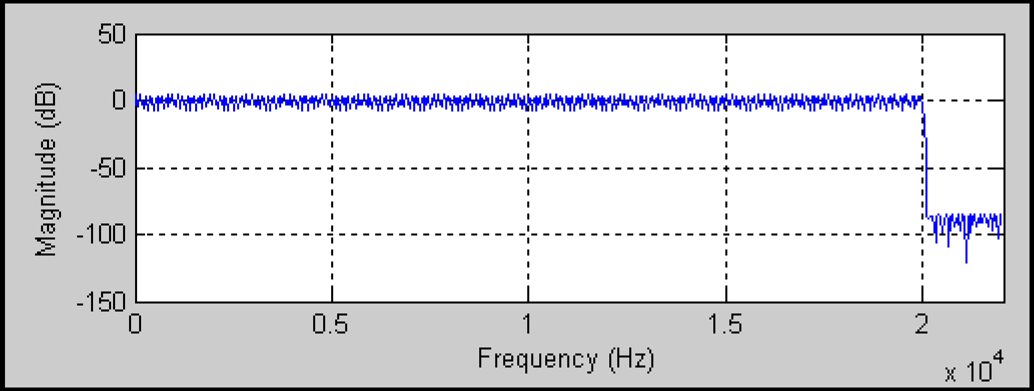
Pre-Echo

- Pass-band ripple can result in pre-echo
  - Sine wave in frequency domain = Impulse in time domain

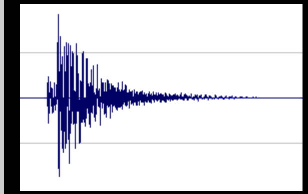


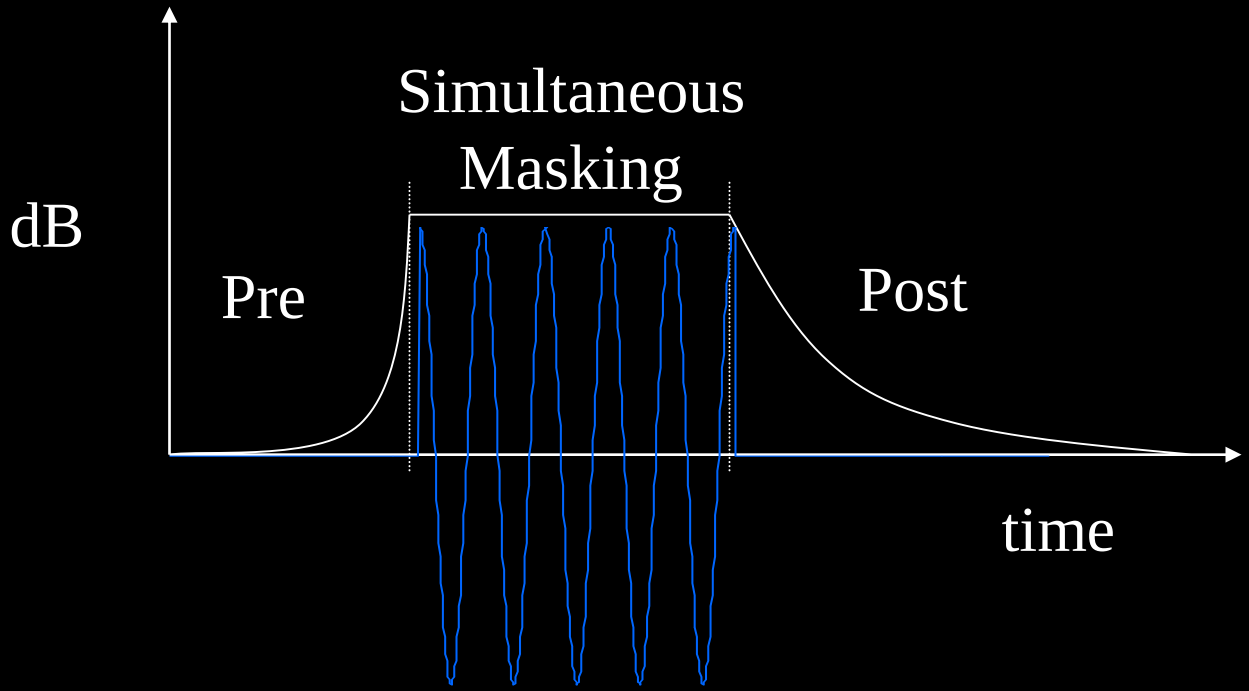
Pre-Echo





Magnitude (dB)
50
0
-50
-100
-150
0
0.5
1
1.5
2
Frequency (Hz)
x 10^4

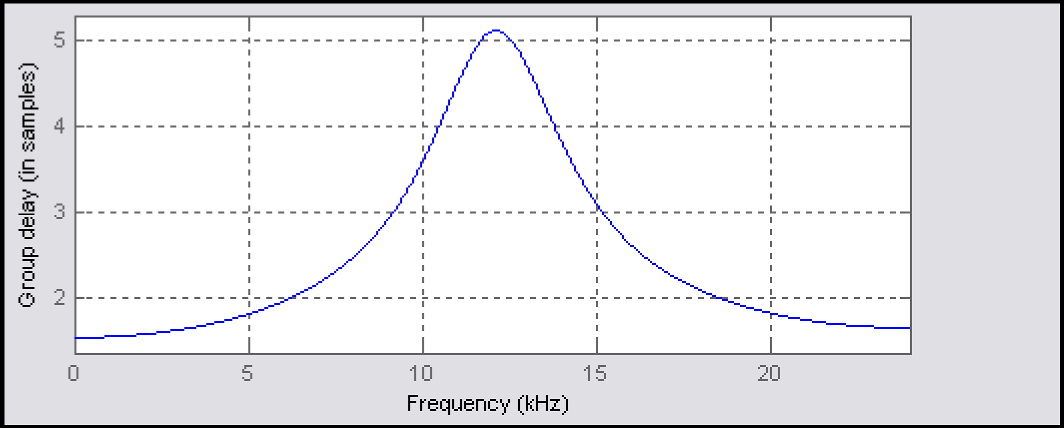




Simultaneous
Masking
dB
Pre
Post
time

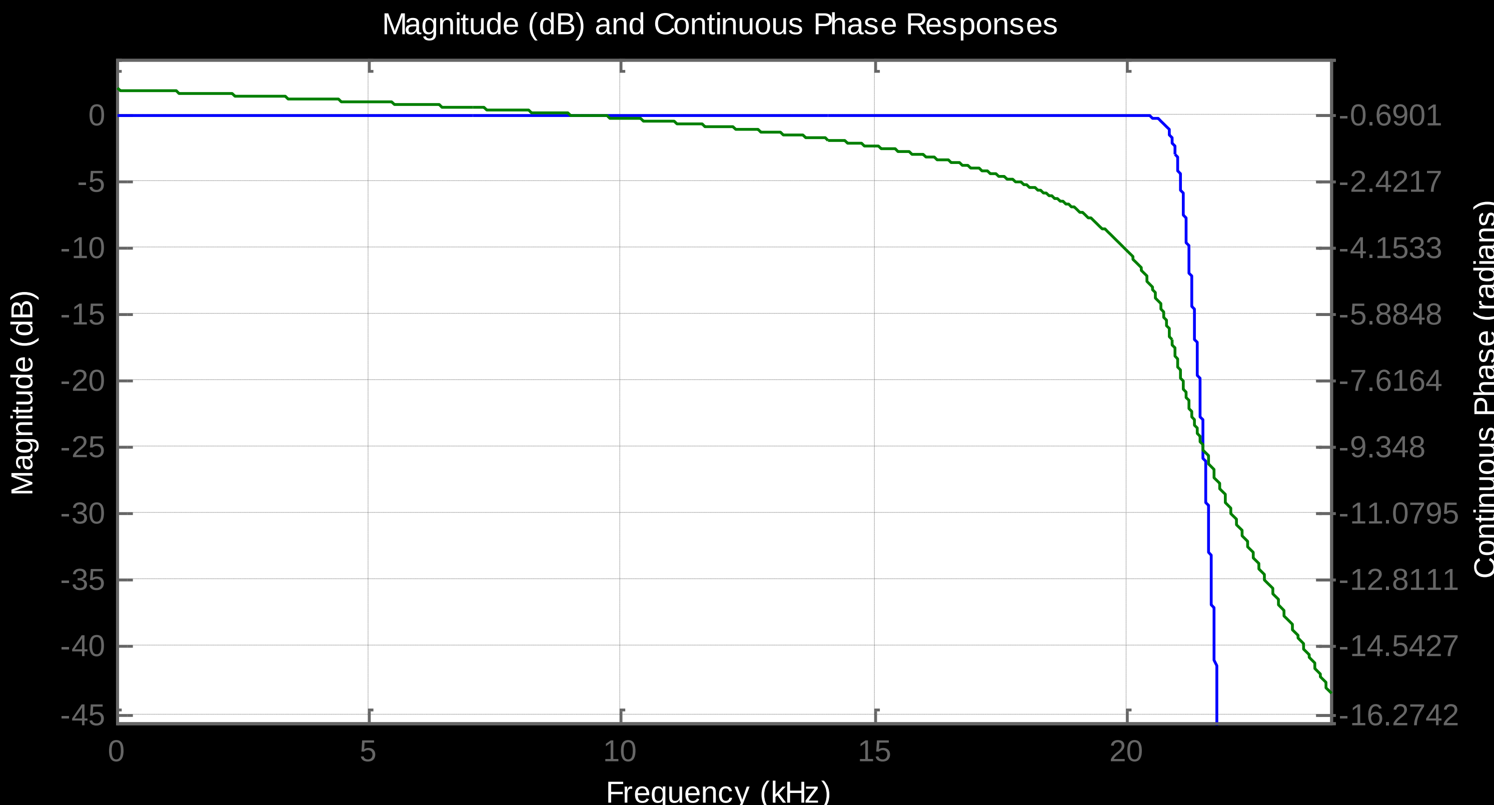
Phase Linearity

- Linear vs. non-linear phase (and resulting group delay)



- Anti-aliasing filter delay (linear or near-linear phase)
  – At 48kHz, 12 samples = 250µs
  – At 192kHz, 12 samples = 62.5µs
- Non-linear phase is not just in digital filters… also in analog filters and mechanical systems! This is where the argument for speakers with extended frequency response comes into play.

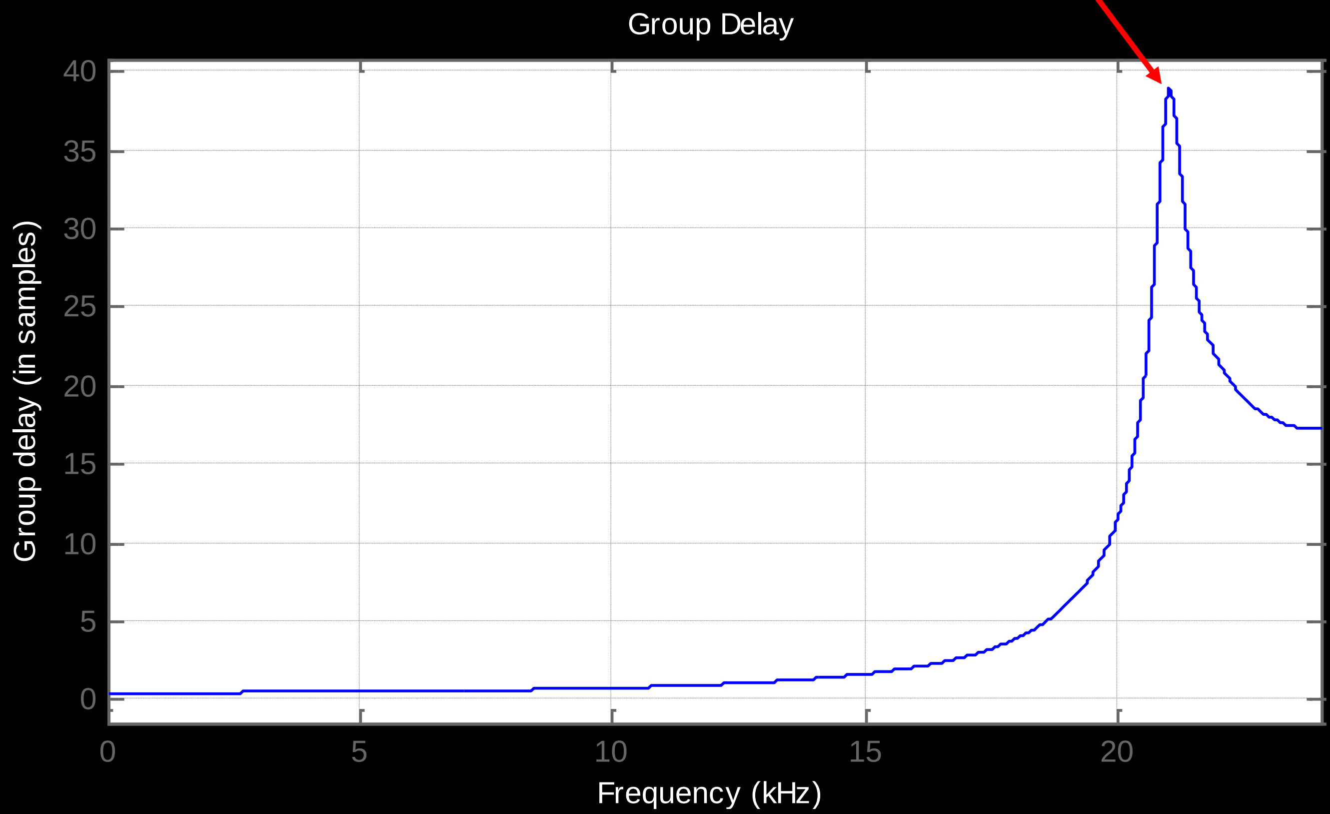
Filters



Fs=48kHz

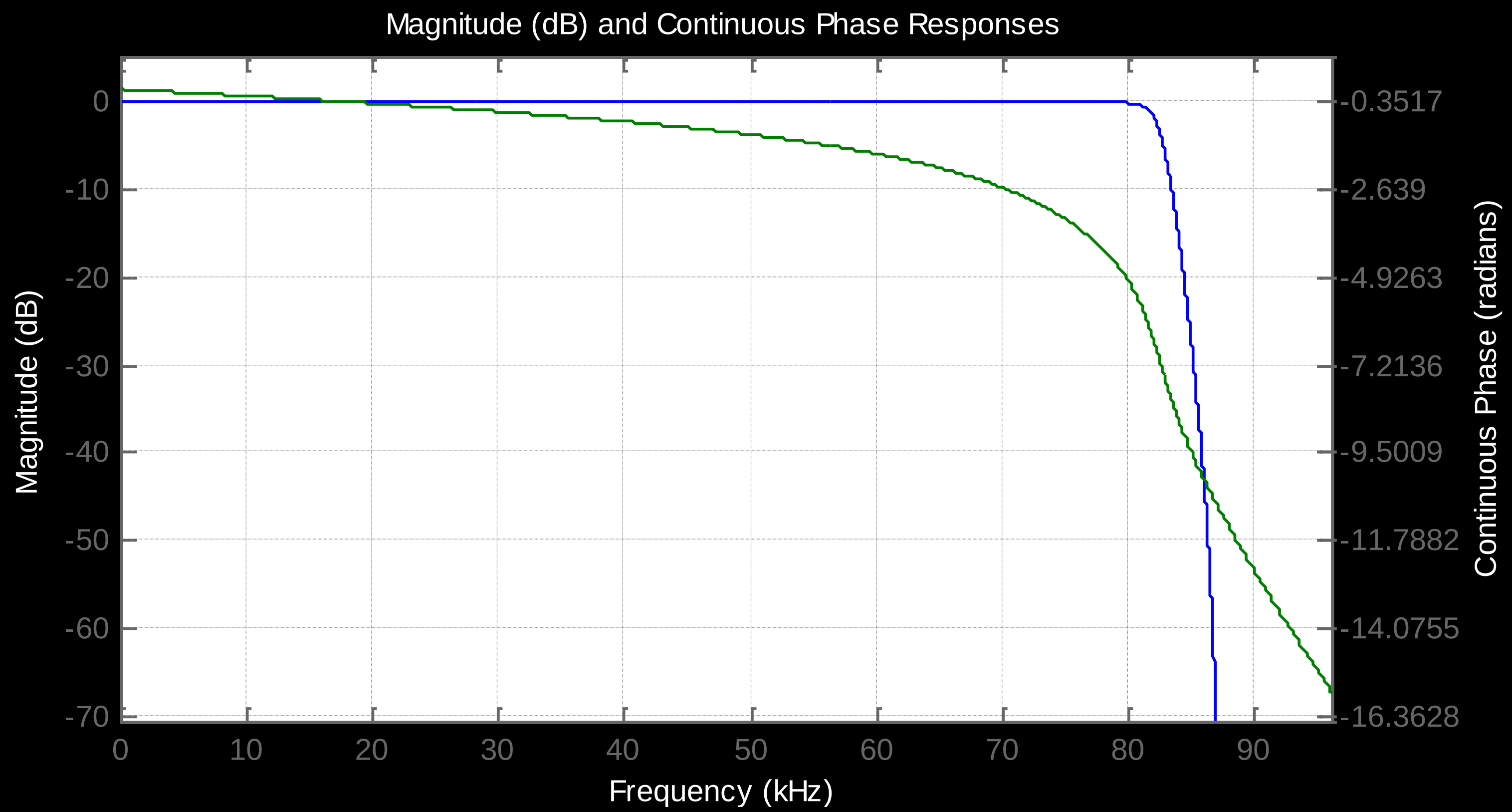
Filters

< 1.0ms of ringing @ Fc



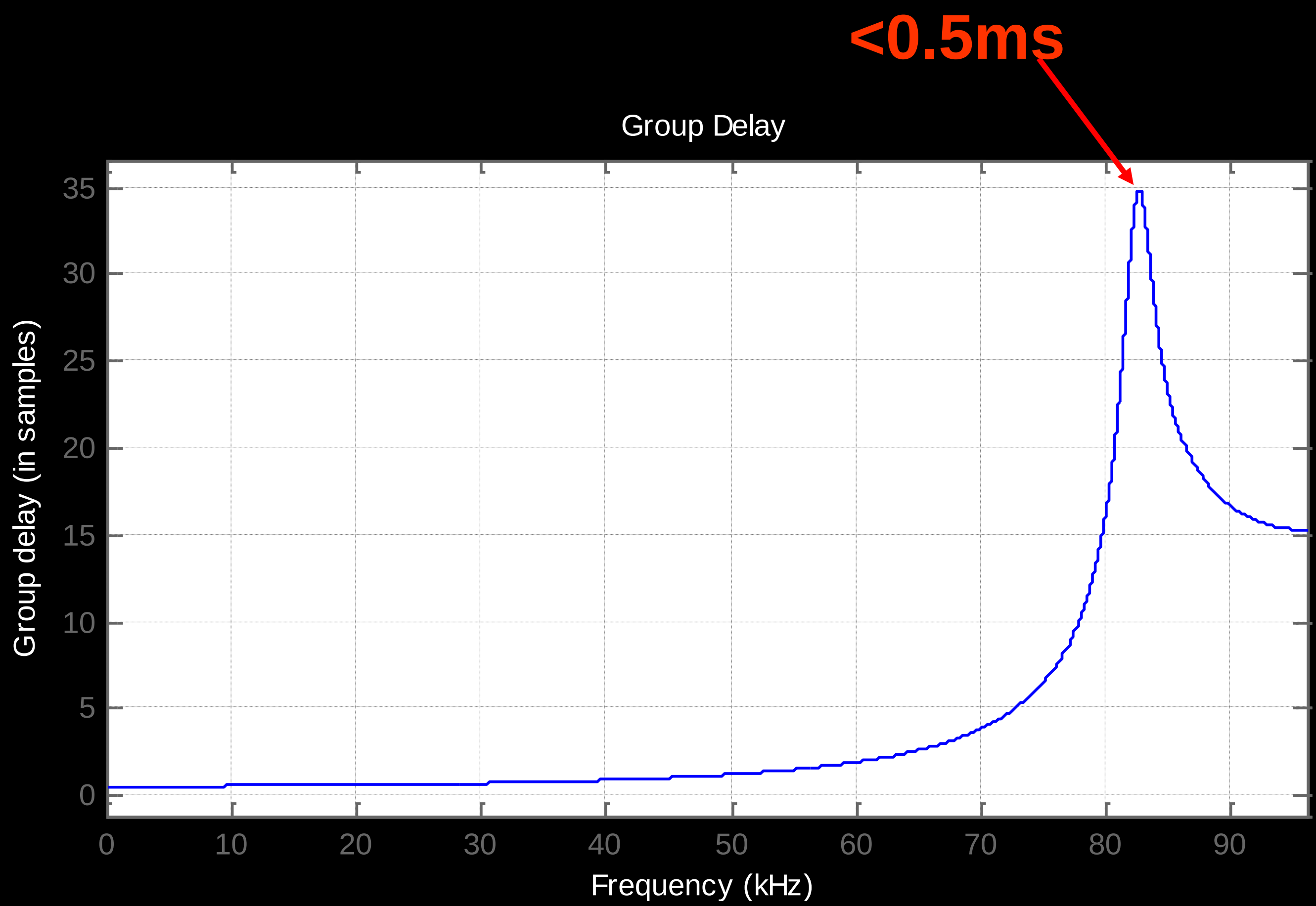
Fs=48kHz

Filters



Fs=192kHz

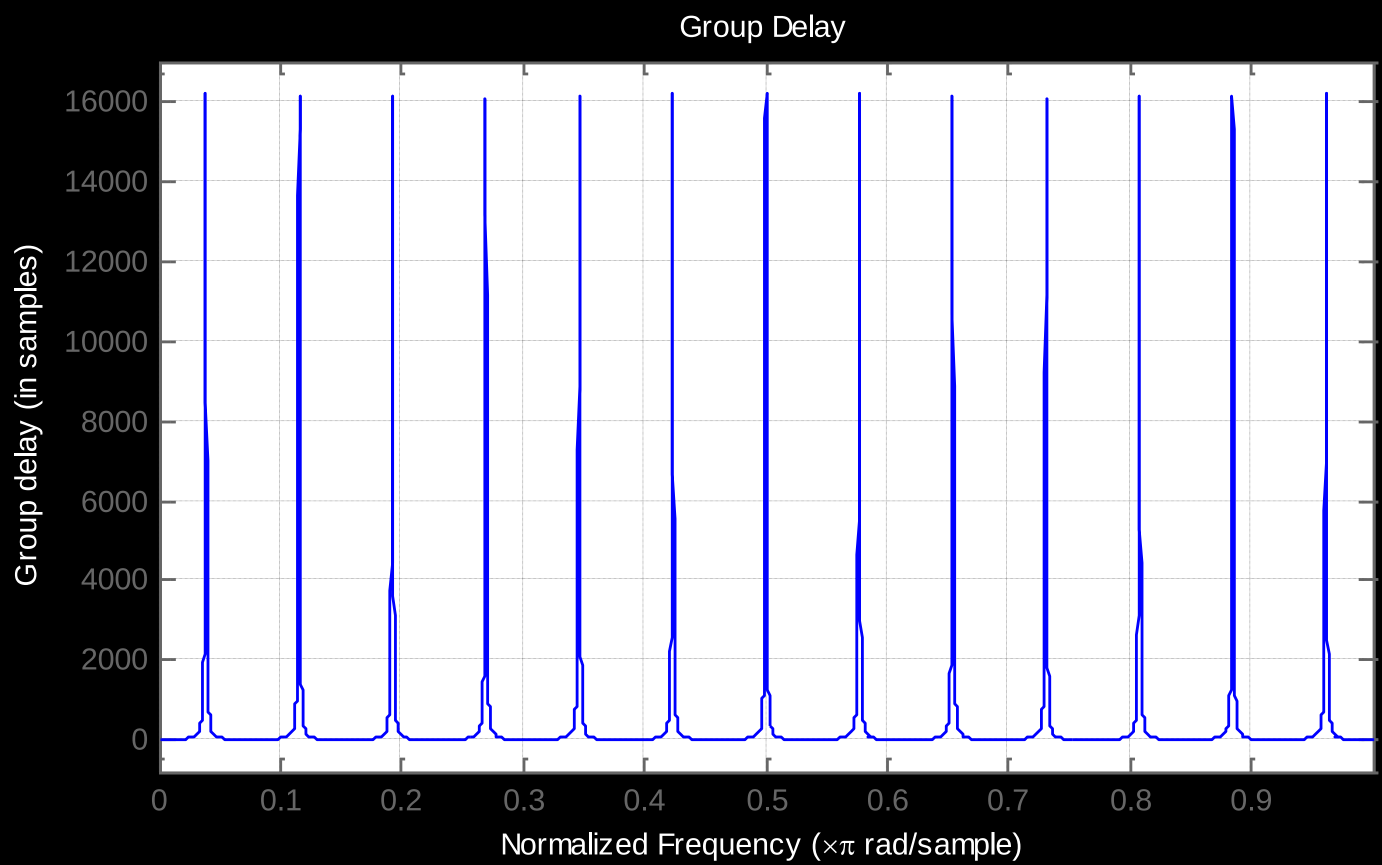
Filters



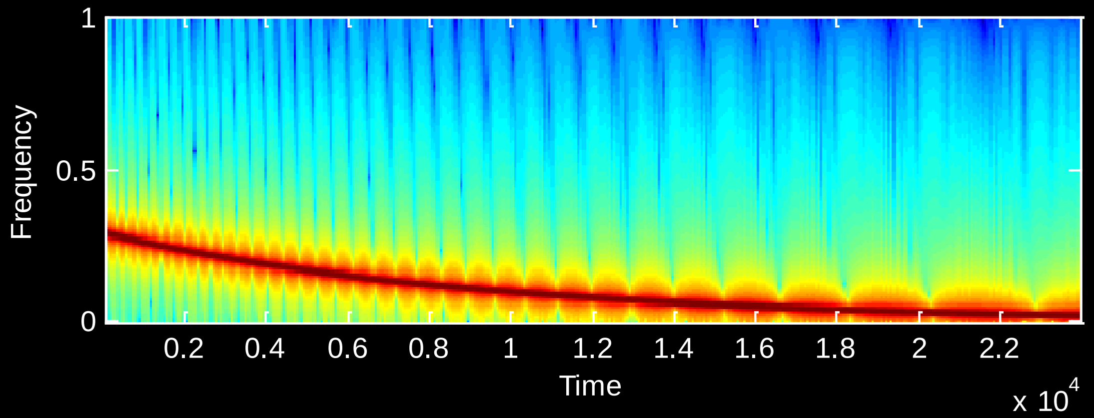
Fs=192kHz

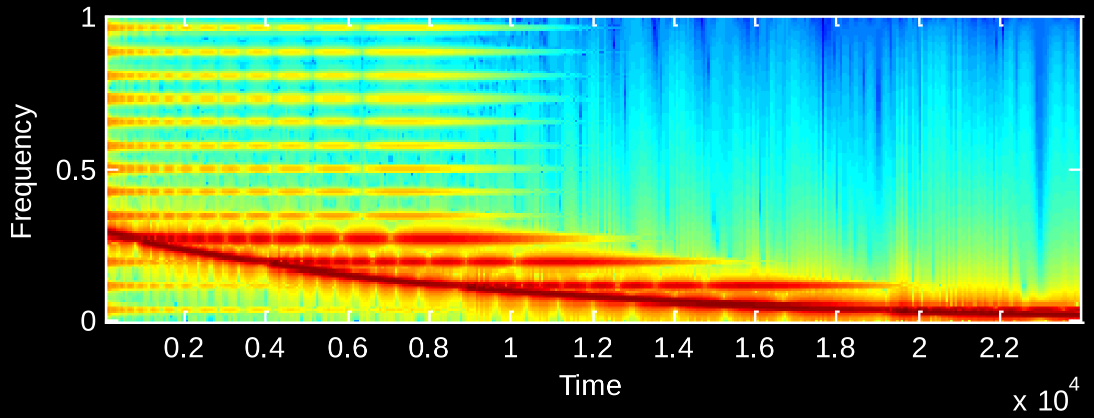
Severe Group Delay

To make it really audible, let's increase the group delay at several frequencies…



Severe Group Delay





Mixing & Monitoring

- Here's where phase becomes critical…
  - You can't hear small phase nonlinearities of a mono signal in an anechoic environment… but in any real condition, you can, especially when you start mixing!

pink allpass

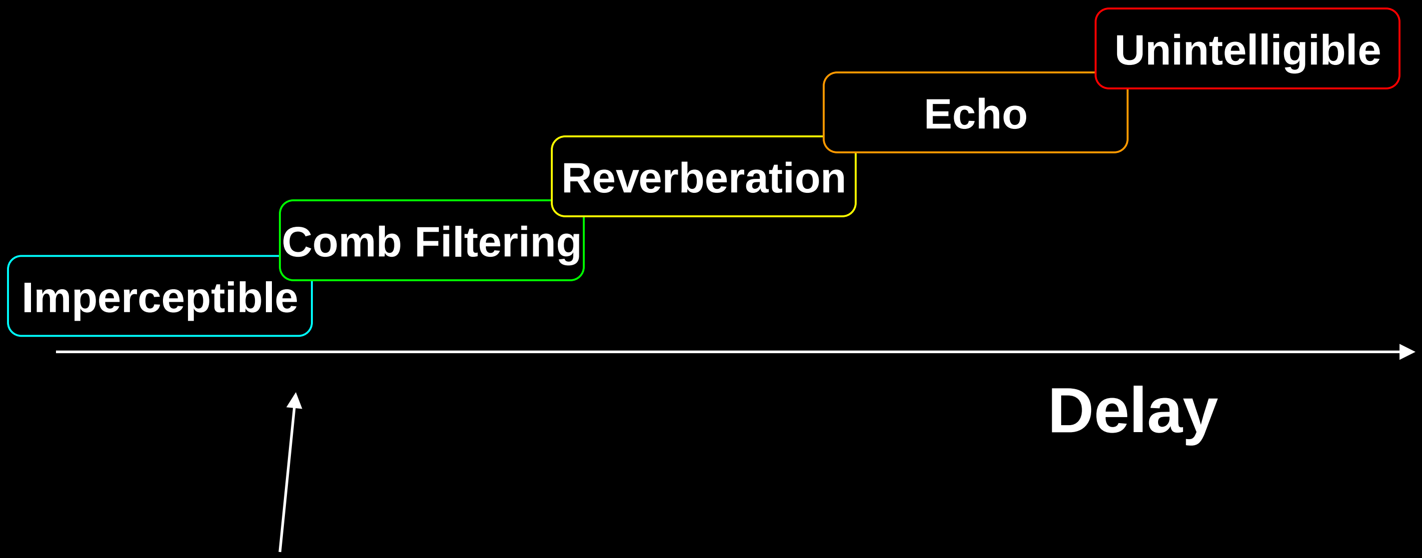
. 2*pink pink+allpass

- Delay
  - How much delay is too much?

Delay

- Doesn’t matter if you don’t know it’s been delayed (i.e. broadcast audio doesn’t arrive instantly)
- But if you can hear the original and the delayed version mixed… comb filtering!
  - But we hear varying degrees of this all the time
- What if we increase the delay?

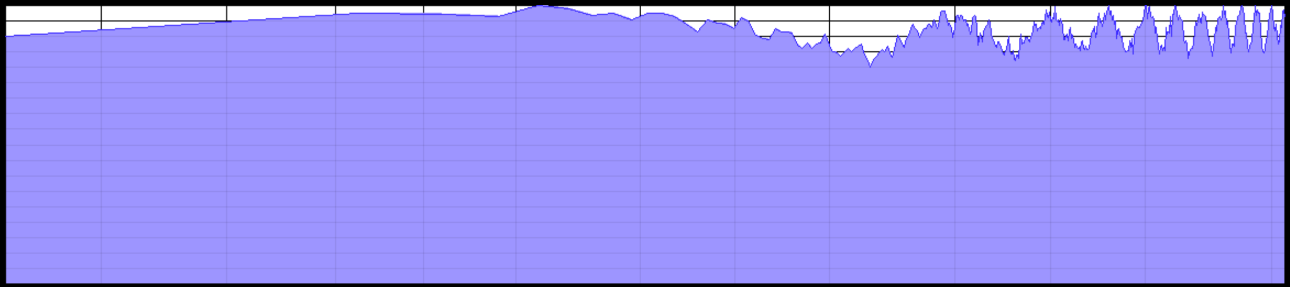
Monitoring with Delay



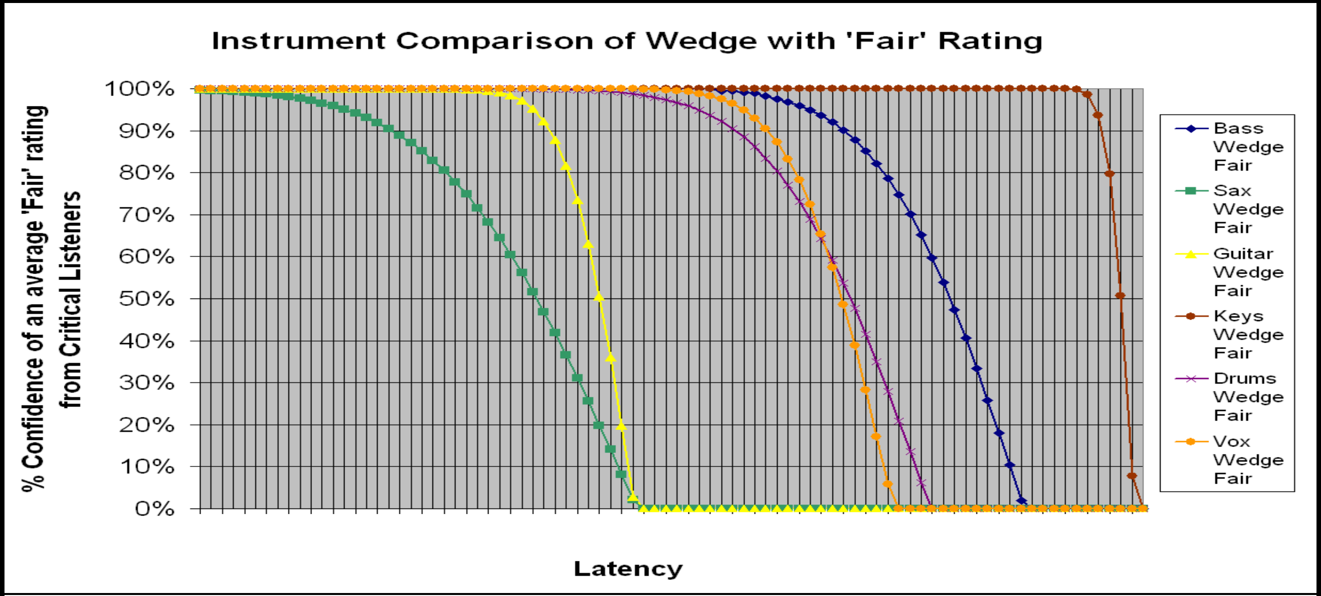
6 samples @ 48kHz = first comb filter null @ 4kHz (latency due to ADC can be audible!)

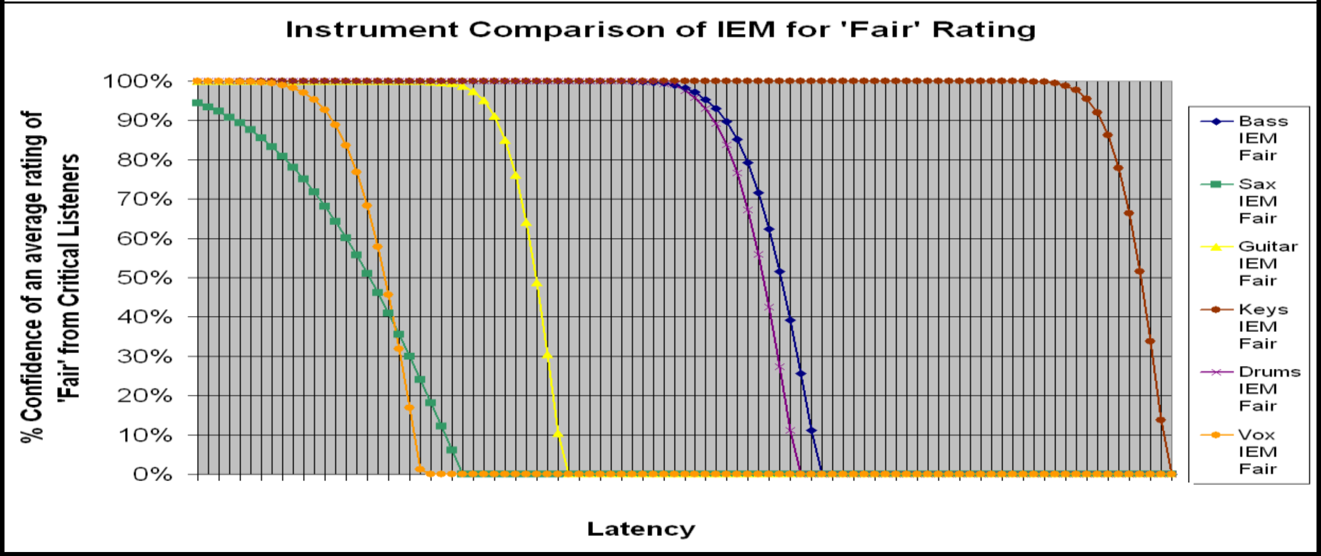
Monitoring with Delay

- If we have a null at 4kHz, the depth of this null is determined by the relative levels of the source and the processed sound
  - Source/Monitor Ratio = 0dB … null = -∞dB
  - Source/Monitor Ratio = ± big … null = small
- The solution – to reduce comb filtering, either keep your monitor mix turned down, or use in-ear monitors with good isolation
- Note: This and following slide use constant group delay



Monitoring with Delay

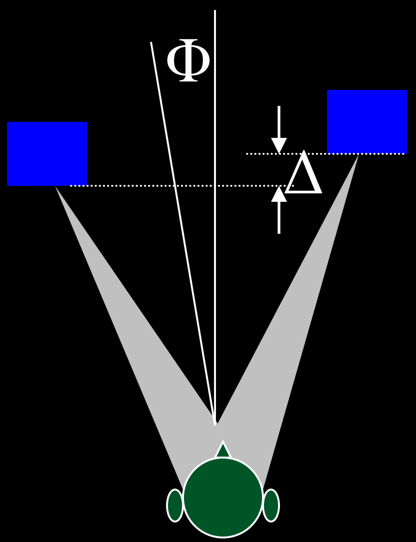




Stereo Imaging

- This question seems to have first appeared around 1980 when some of Sony's designs used alternating samples for stereo converters.

- 48kHz
  - 20.8µs sampling period
  - Δ = 6.9mm per sample ; Φ = 1.9°
- 96kHz
  - 10.4µs sampling period
  - Δ = 3.5mm per sample ; Φ = 0.95°
- 192kHz
  - 5.2µs sampling period
  - Δ = 1.7mm per sample ; Φ = 0.47°



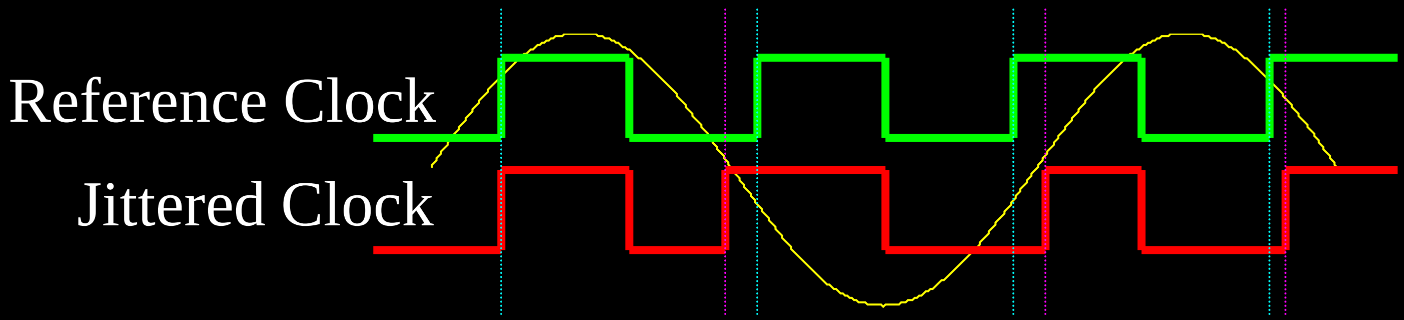
Stereo Imaging

- Most research shows that the JND for IPD is approximately 10μs (for clicks and/or very low frequencies)… although some research suggests as little as 2μs (Blauert)
- The timing of the ADC and DAC are the most critical factors here
  - Use the same converters for everything where possible (i.e. same anti-alias/anti-imaging filters)
  - Make sure they are based on the same clock signal
- In any case, these image shifts will be no larger than those caused by turning your head just slightly (< 2°)

Why Higher Sampling Rates Are Worse

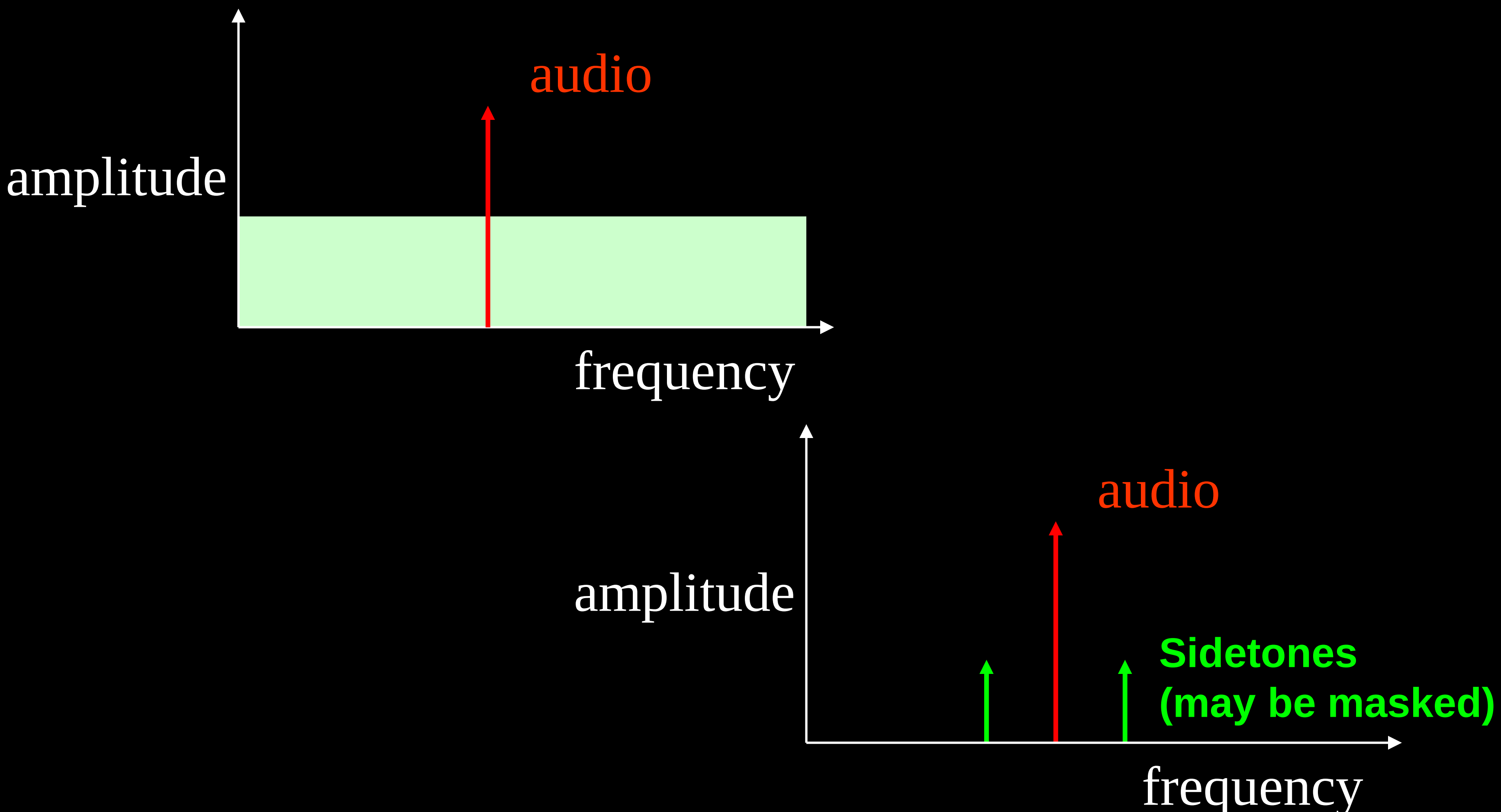
- Computational complexity & memory constraints
  – 192kHz requires 4x more processing than 48kHz
    - 30-band GEQ: 172 MIPS -vs- 43 MIPS
  – Buffers often must also be extended to 4x the length at 48kHz
    - 10ms (24bit audio): 46kb -vs- 11.5kb
- Jitter
  – Magically appearing sounds!

Jitter

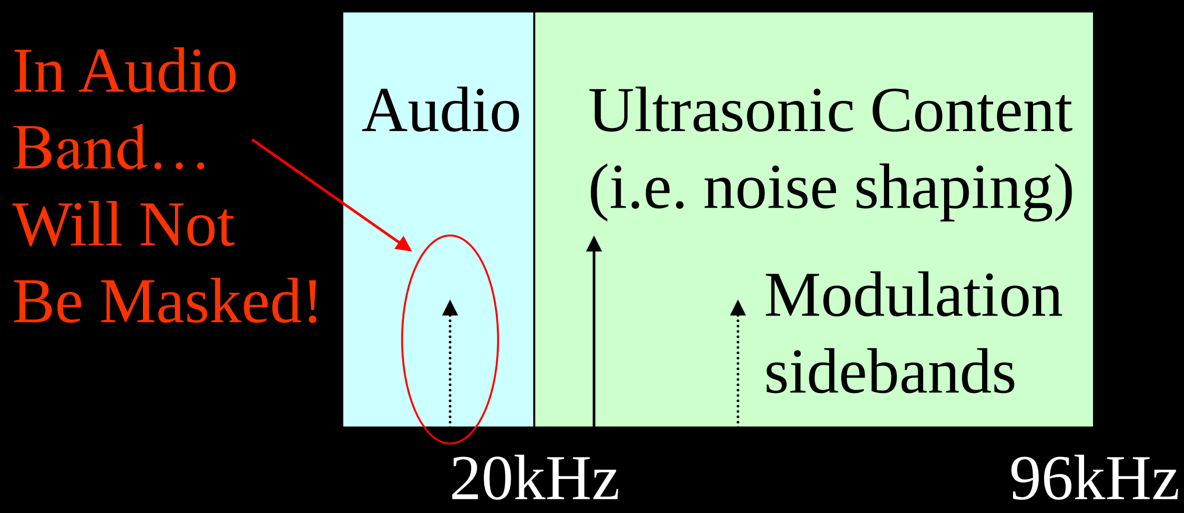


- Common Causes
  - Temperature variation of crystal
  - Inaccurate PLL for frequency/phase conversion
- Effects
  - Degraded audio quality (THD+N)… especially if ADC clock is bad!

Jitter Spectra



Jitter @ Fs=192kHz



Julian Dunn, Audio Precision Application Note #5: Measurement Techniques for Digital Audio, Published by Audio Precision, Inc., 2004.

Summary

- Audible differences between 44.1, 48, 96, 192kHz sampling rates are all due to issues other than Nyquist itself.
- For better sound, use better anti-alias/anti-imaging filters or increase sample rate… Both methods produce similar results.
- Be careful with phase nonlinearities in your audio band.
- Sample rate *may* affect stereo imaging, but probably not much.
- Sample rate drastically affects computational requirements.
- Keep your clocks clean, especially when using high sample rates.

References

- Dunn, Julian. *Anti-alias and anti-image filtering: The benefits of 96kHz sampling rate formats for those who cannot hear above 20kHz.* 104th AES Convention, May 1998.
- Oohashi, et al. *Inaudible high-frequency sounds affect brain activity: hypersonic effect.* Journal of Neurophysiology 83: 3548–3558, 2000.
- Julian Dunn, *Audio Precision Application Note #5: Measurement Techniques for Digital Audio*, Published by Audio Precision, Inc., 2004.
- Blauert, Jens, *Spatial Hearing*, *Revised Edition.* MIT Press, Cambridge, MA. 1997.