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Sound check

Analysis of Piano Tones Using an Inharmonic Inverse Comb Filter

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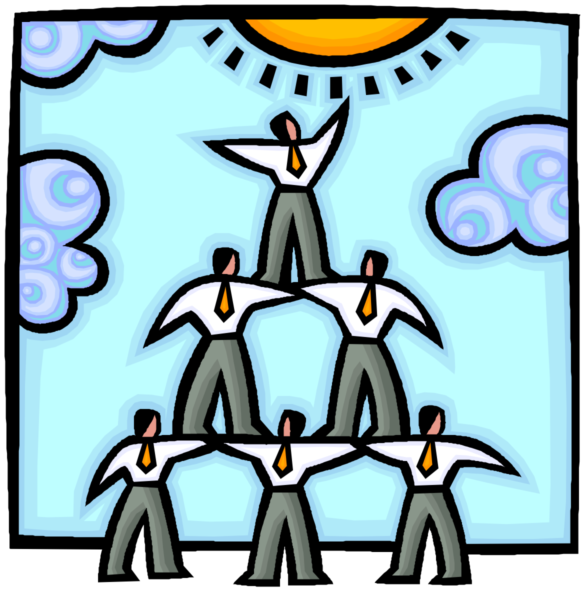
Outline of the Presentation

- Introduction and motivation
- Fractional-delay inverse comb filter (ICF)
- Design of inharmonic ICFs
  - FIR
  - IIR
- Application examples
- Conclusions

Introduction

- Analyze inharmonic piano tones with a simple filtering-based method
  - Cancel all partials → residual signal
  - Select single partials
- Continuation to earlier work
  - Analysis of harmonic musical signals
    (Välimäki *et al.* 2004, Välimäki *et al.* DAFx-07, Lehtonen *et al.* 2008)

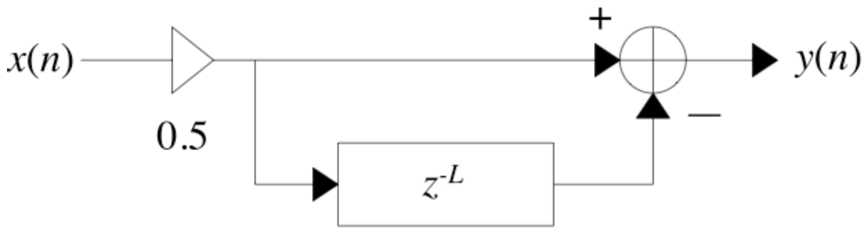


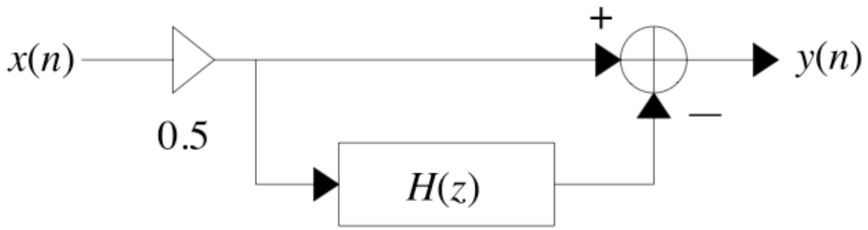
Motivation

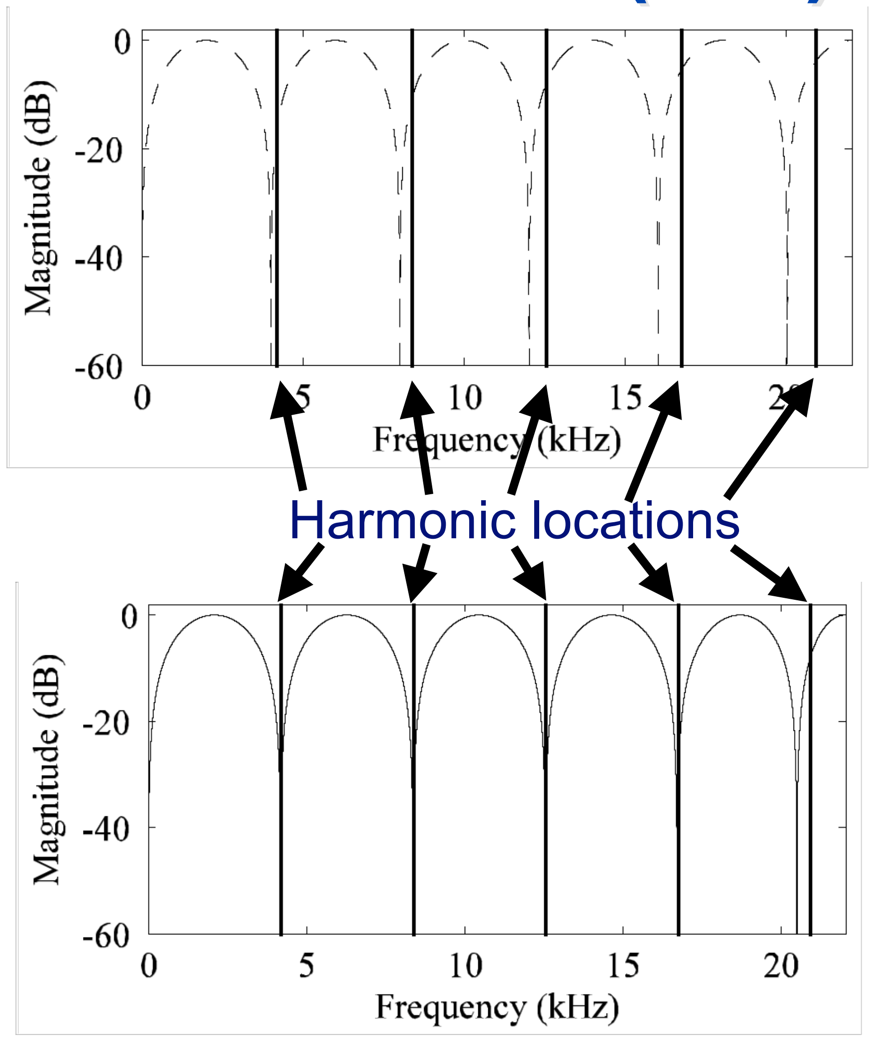
- The Ultimate Goal: physically informed sound synthesis of the piano
- Need for parameters and other information from recorded tones
  - Partial amplitudes, decay times
  - Characteristics of the residual
- Simple and effective way to cancel partials or select them for parameter extraction?

Fractional-delay Inverse Comb Filter (ICF)

- Delay line length $L = f_s/f_0$
  - f_s = sampling rate (44.1 kHz)
  - f_0 = fundamental frequency







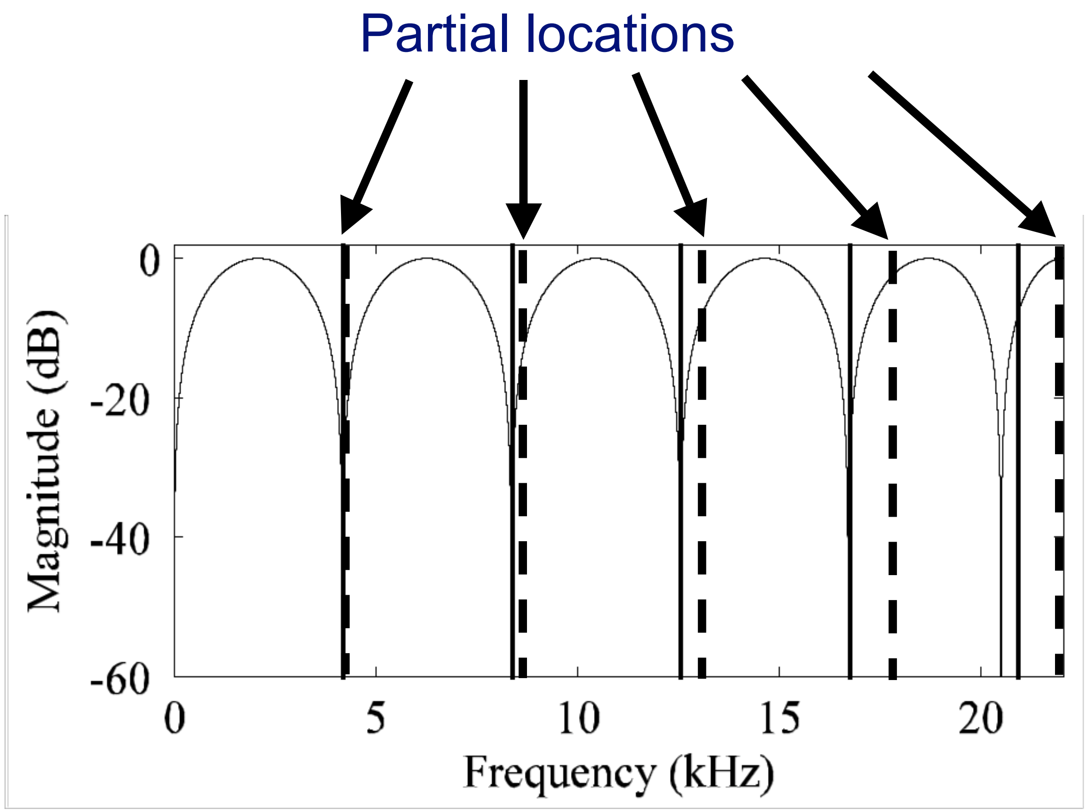
Use e.g. Thiran or Lagrange filter design to implement fractional delay (Välimäki *et al.* DAFx-07, Lehtonen *et al.* 2008)

Inharmonic ICF

- Piano tones are inharmonic!
- Inharmonicity is caused by dispersion
- Partial frequencies f_k can be computed from (Fletcher *et al.* 1962)

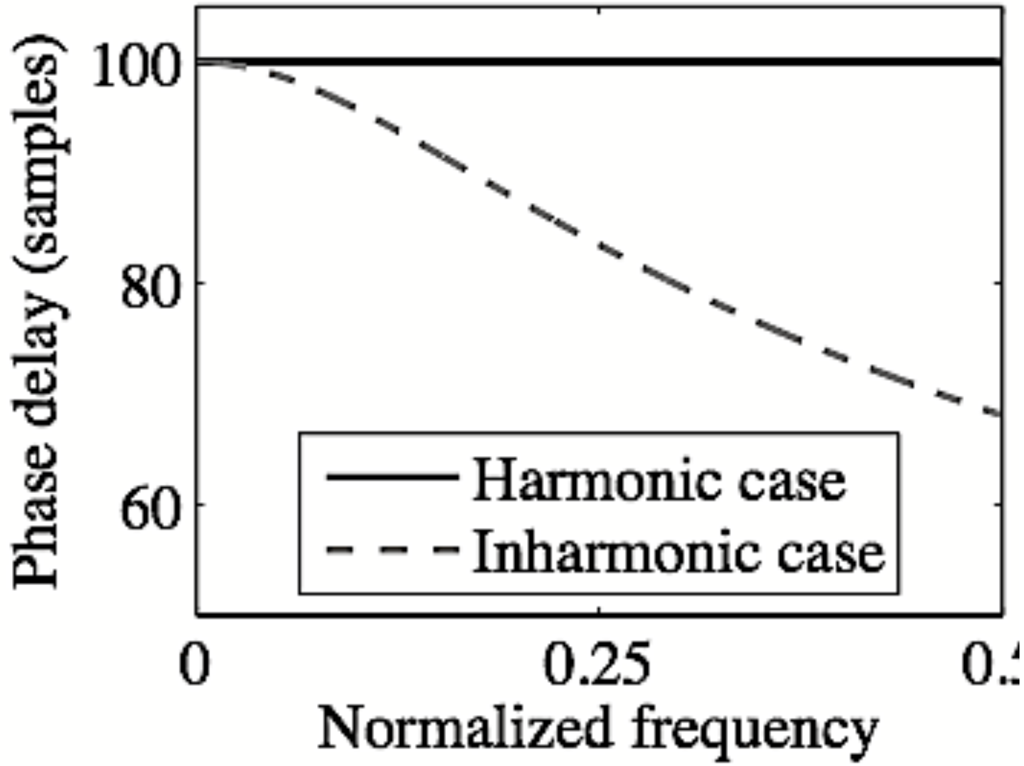
$$f_k = kf_0\sqrt{1+k^2B}$$

  - *B* is inharmonicity coefficient (assumed to be known)



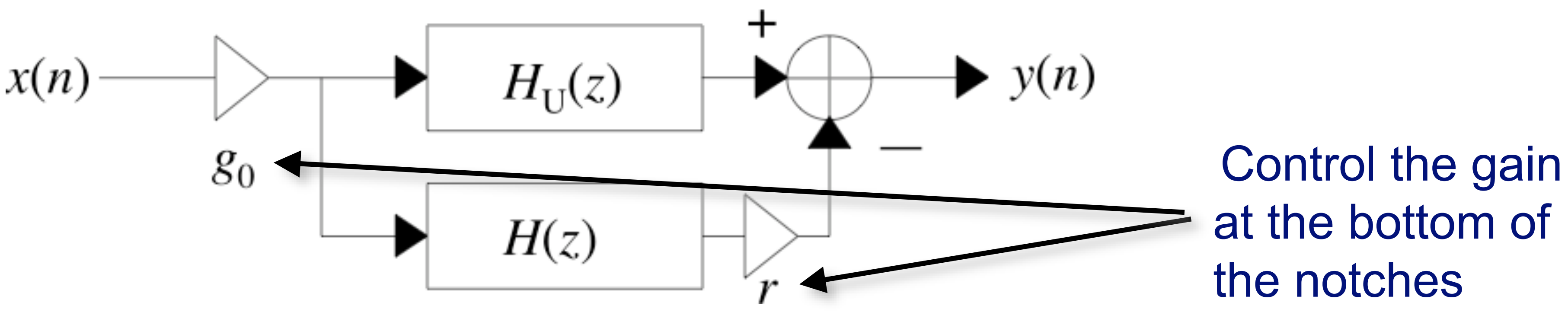
Properties of Inharmonic ICF

- The filter in the ICF needs to have frequency-dependent phase delay
- Many design techniques approximate this behavior (e.g. Rocchesso and Scalcon 1996, Testa *et al.* 2004, Bensa *et al.* 2005, Rauhala and Välimäki 2006 etc.)
- For signal analysis, more accuracy is needed



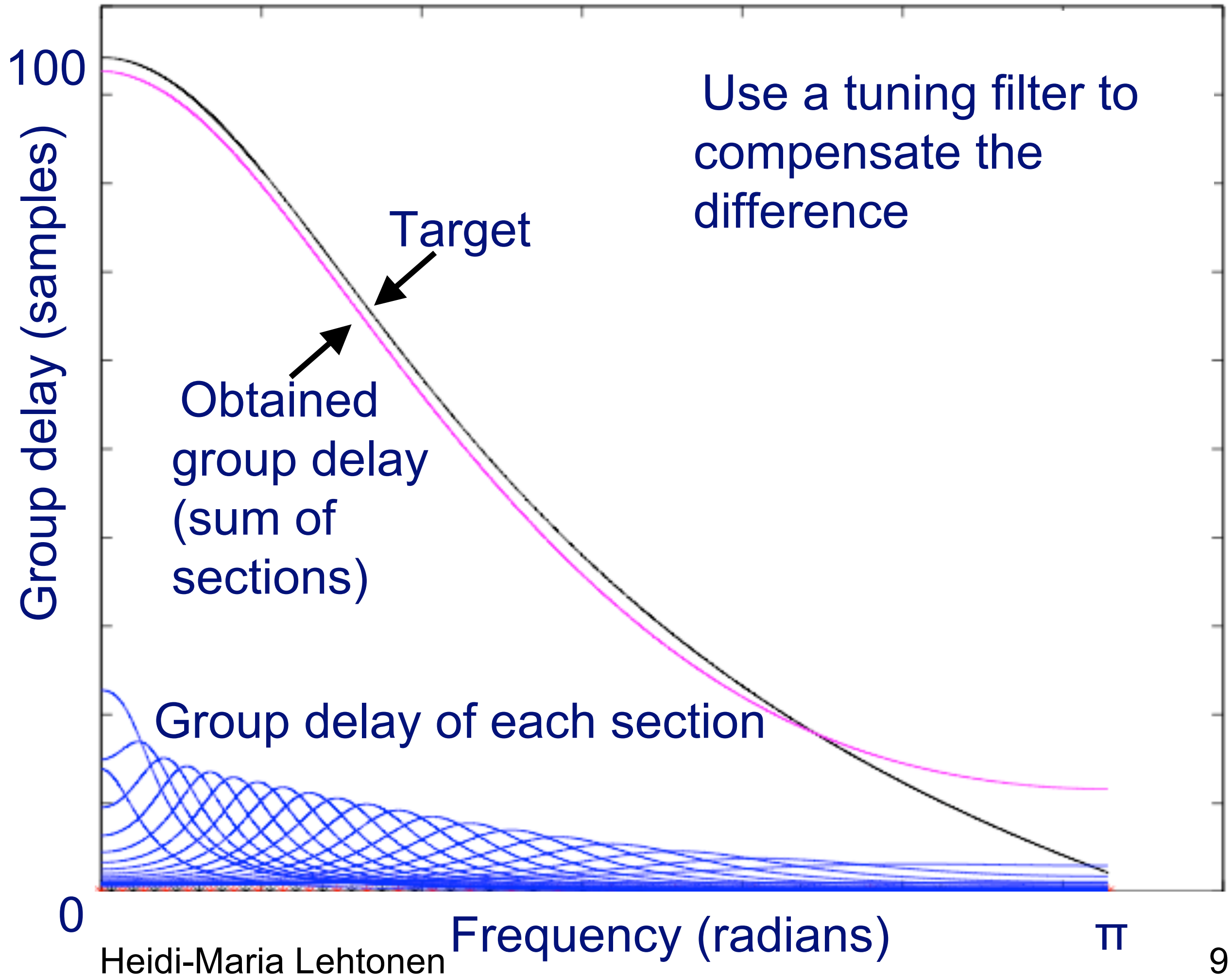
Inharmonic FIR Filter

- Design phase and magnitude response: $H(\omega)=|H(\omega)|e^{j\theta(\omega)}$
  - Phase is a multiple of 2π radians at partial frequencies f_k
  - Magnitude response imitates a lowpass filter (passband 0-20 kHz)
- Use inverse DFT to obtain filter coefficients from $H(\omega)$
- Linear-phase LP filter $H_U(z)$ is used to synchronize the signals



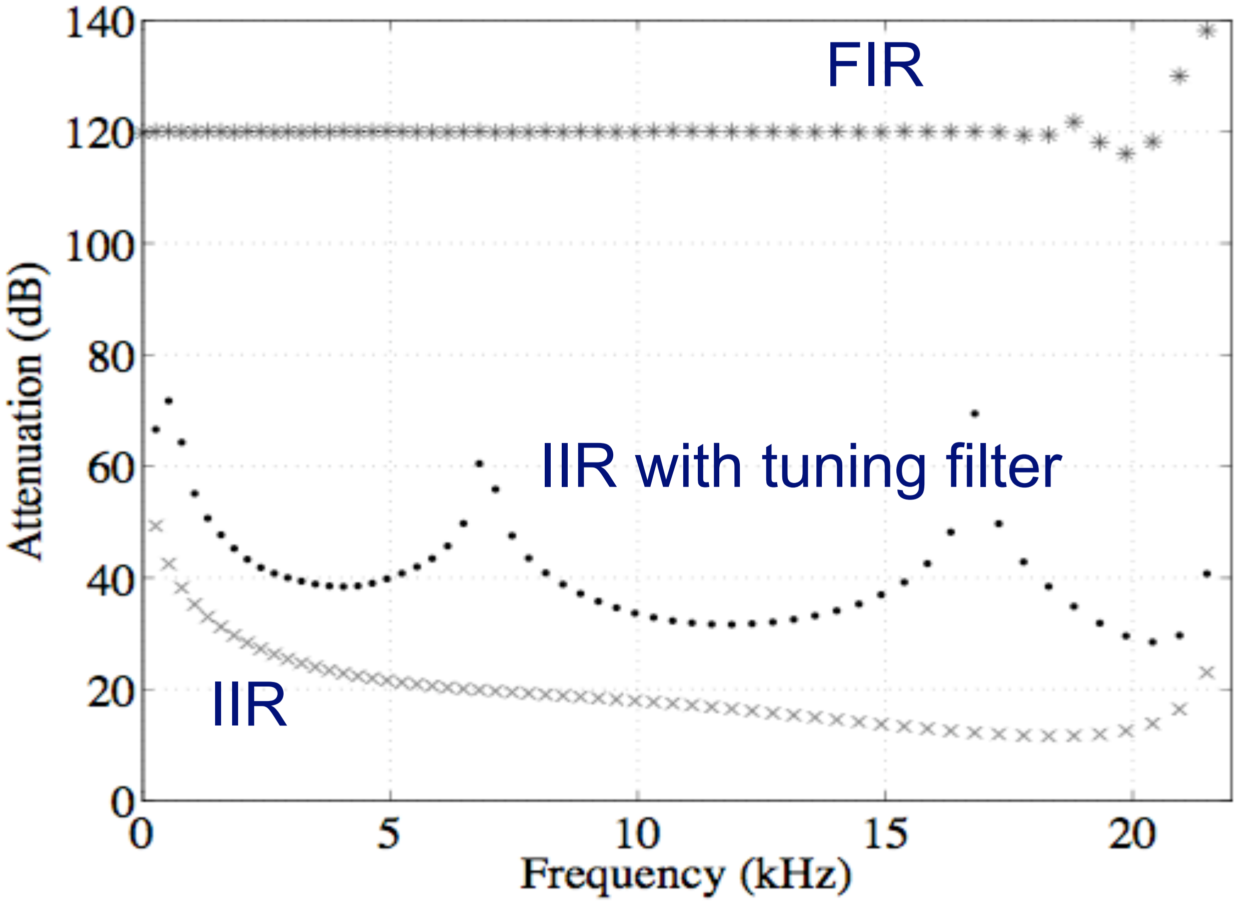
Inharmonic IIR Filter (Abel and Smith DAFx-06)

- Nonparametric technique:
  - Divide the desired group delay area into sections of 2π
  - Assign a pole-zero pair to each section
  - Each pair contributes area of 2π to the total group delay



Inharmonic FIR vs. IIR Filter

- Attenuation at partial frequencies:
  - * FIR of order 1000
  - • IIR, 30 biquads and tuning filter of order 29
  - x IIR, 30 biquads
- Filters are designed for C4
  - – f_0 = 261.6 Hz
  - – B = 3.0x10^{-4}

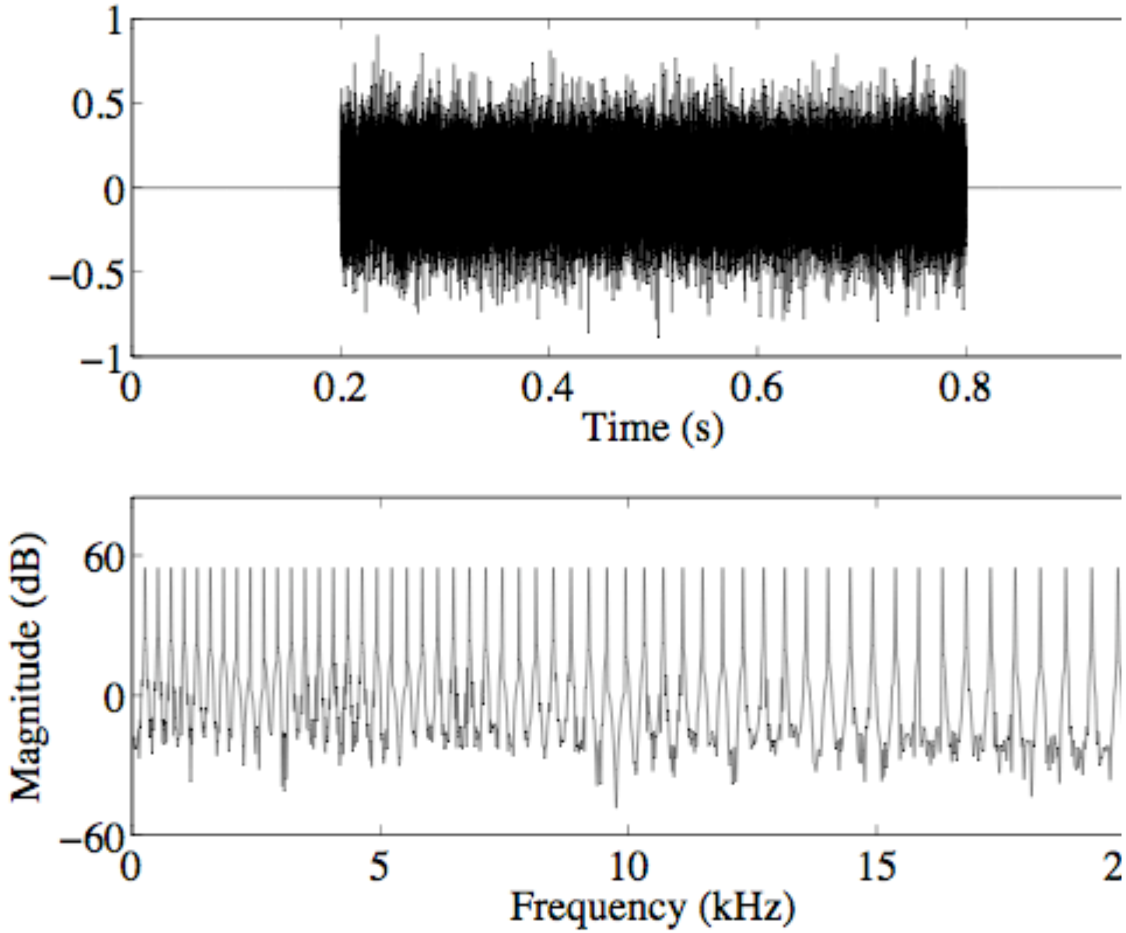


Harmonic Extraction Filter (HEF)

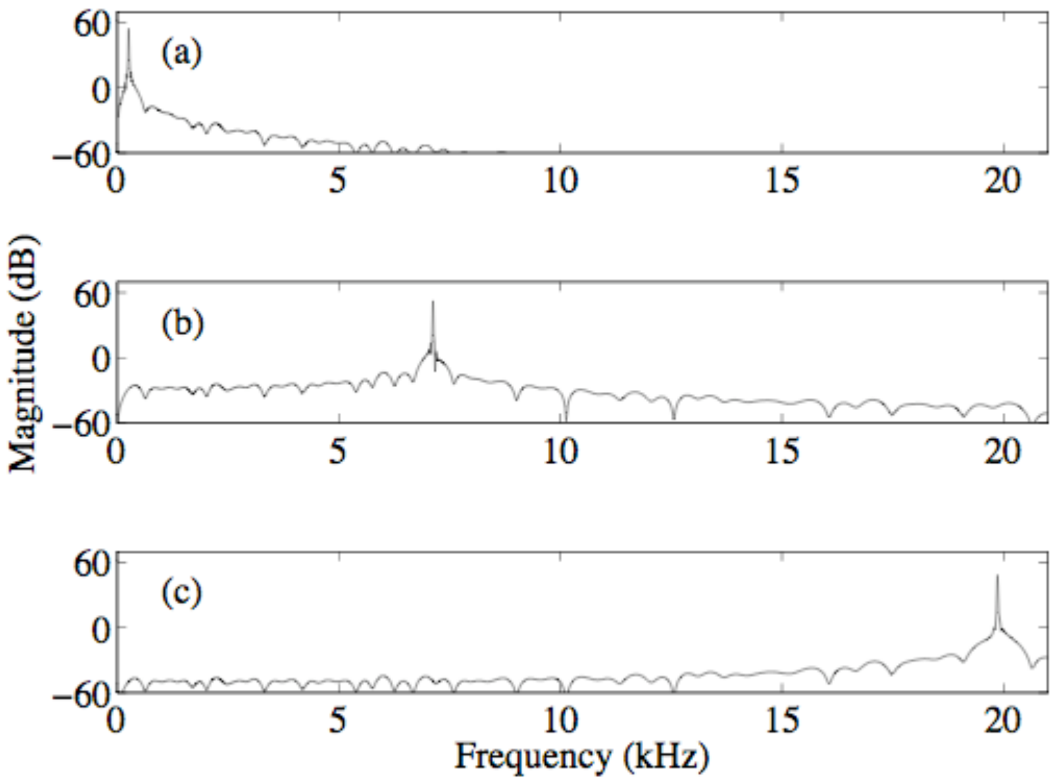
- Select single harmonics by cascading a resonator with the ICF structure (Välimäki *et al.* DAFx-07, Lehtonen *et al.* 2008)
- The pole of the resonator cancels one zero of the ICF in the *z*-plane
  - One partial is preserved while the others are canceled

Application #1: Harmonic Extraction

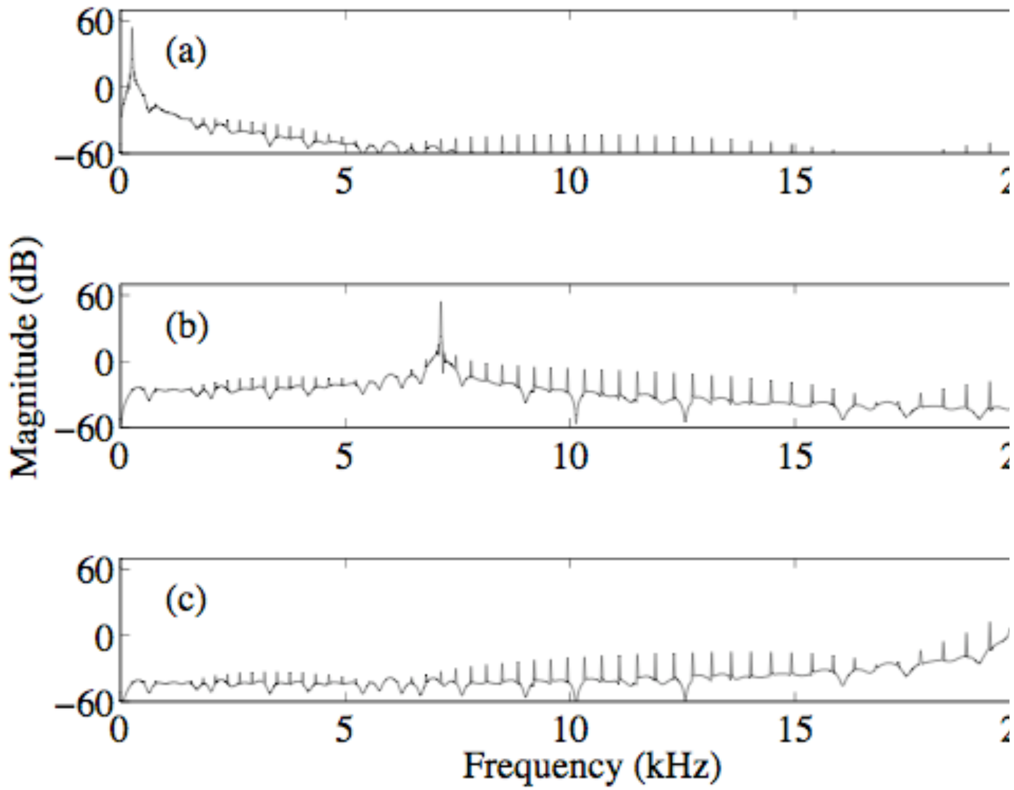
- Extract single harmonics (#1, #25, #55) from a synthetic test signal
- Signal is a sum of 58 sinusoids
  - f_0 = 261.626 Hz (C4)
  - B = 2.9936x10^{-4}



Application #1: Harmonic Extraction



Inharmonic ICF with FIR

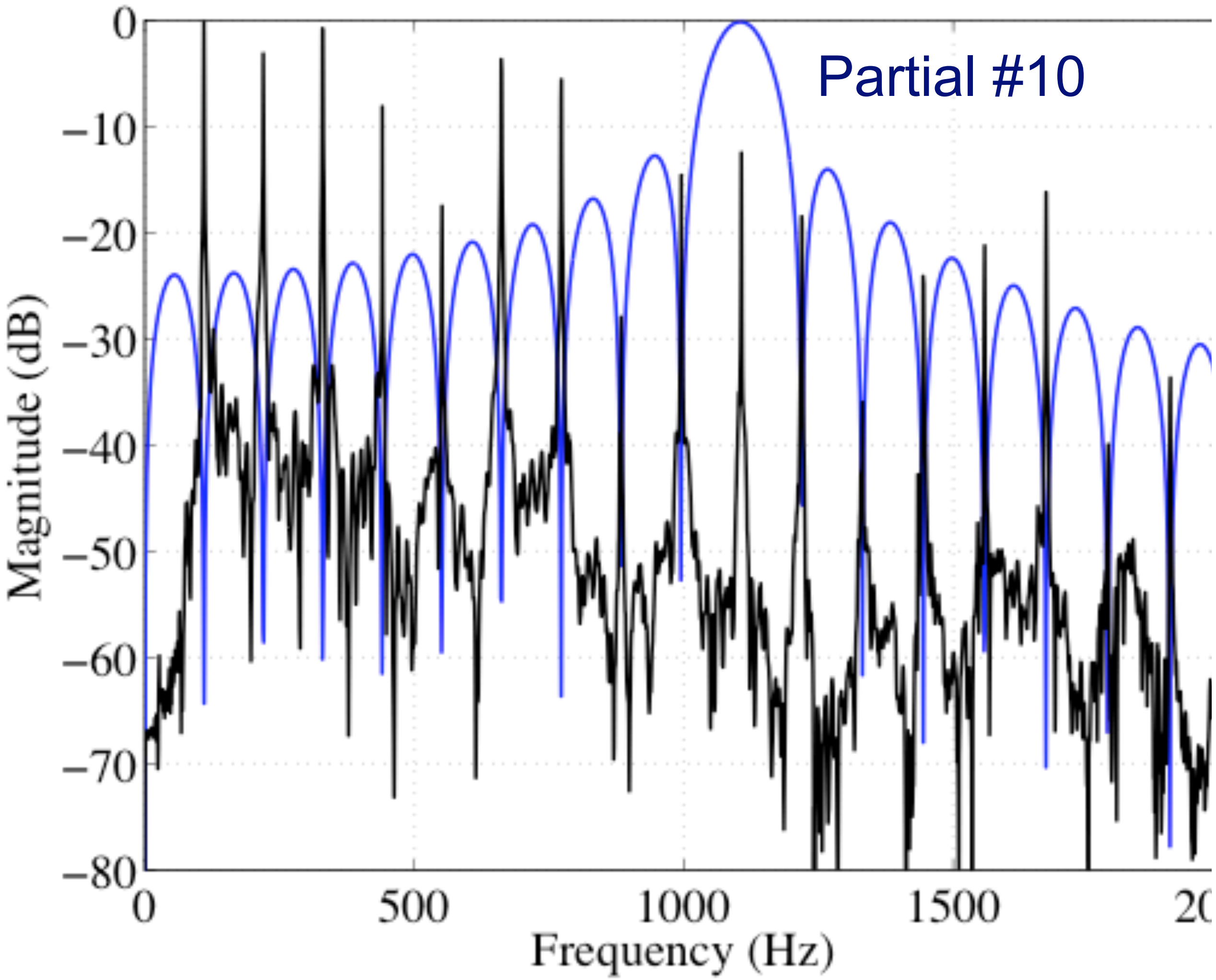


Inharmonic ICF with IIR

Application #2: Partial Extraction from Real Piano Tones

- Select partials from the piano tone A2
- Use ICF with FIR
  - Spectrum of the tone
  - Response of the filter

Original tone and 10 first partials



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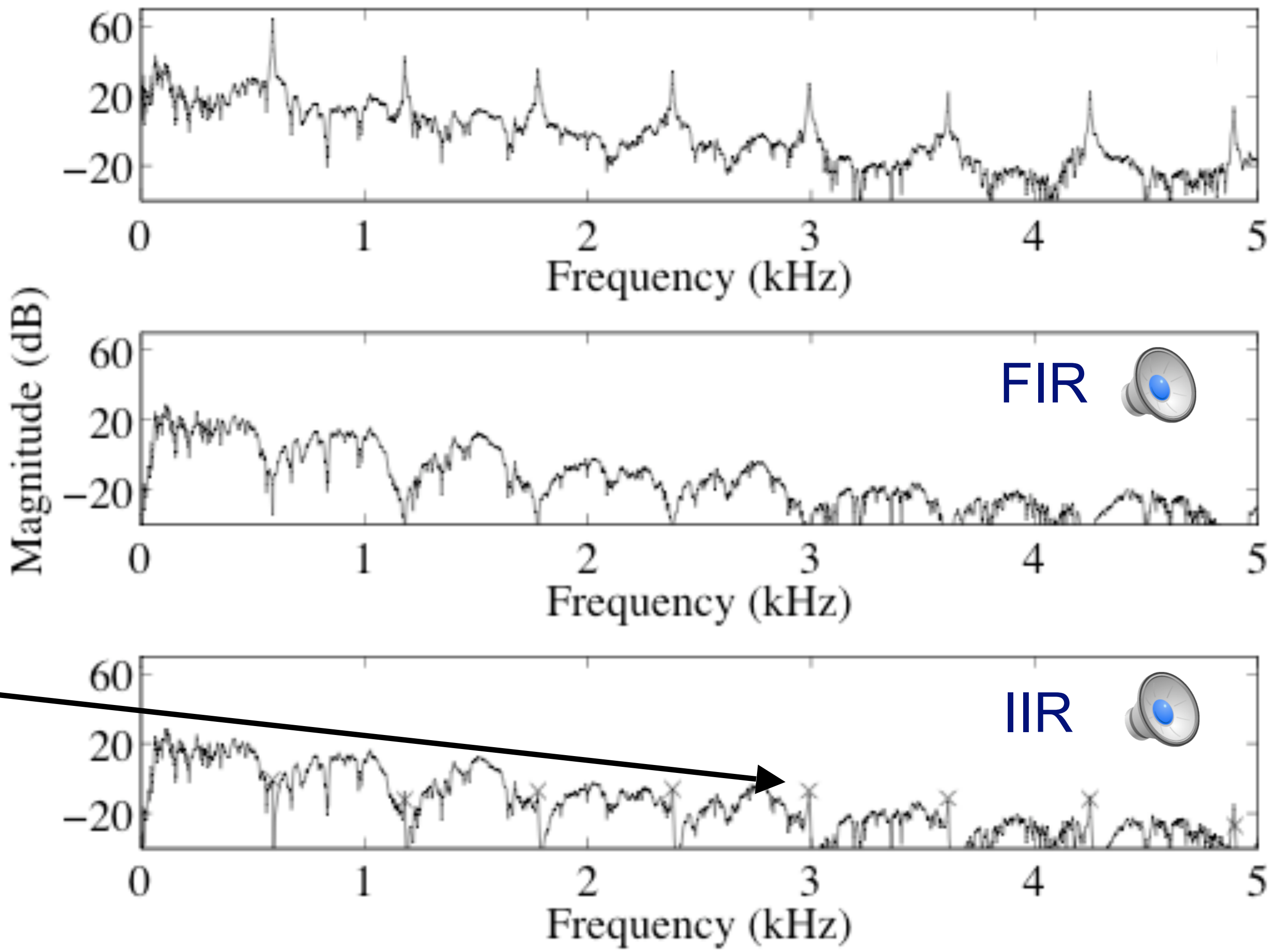
Application #3: Residual Signal of a Real Piano Tone

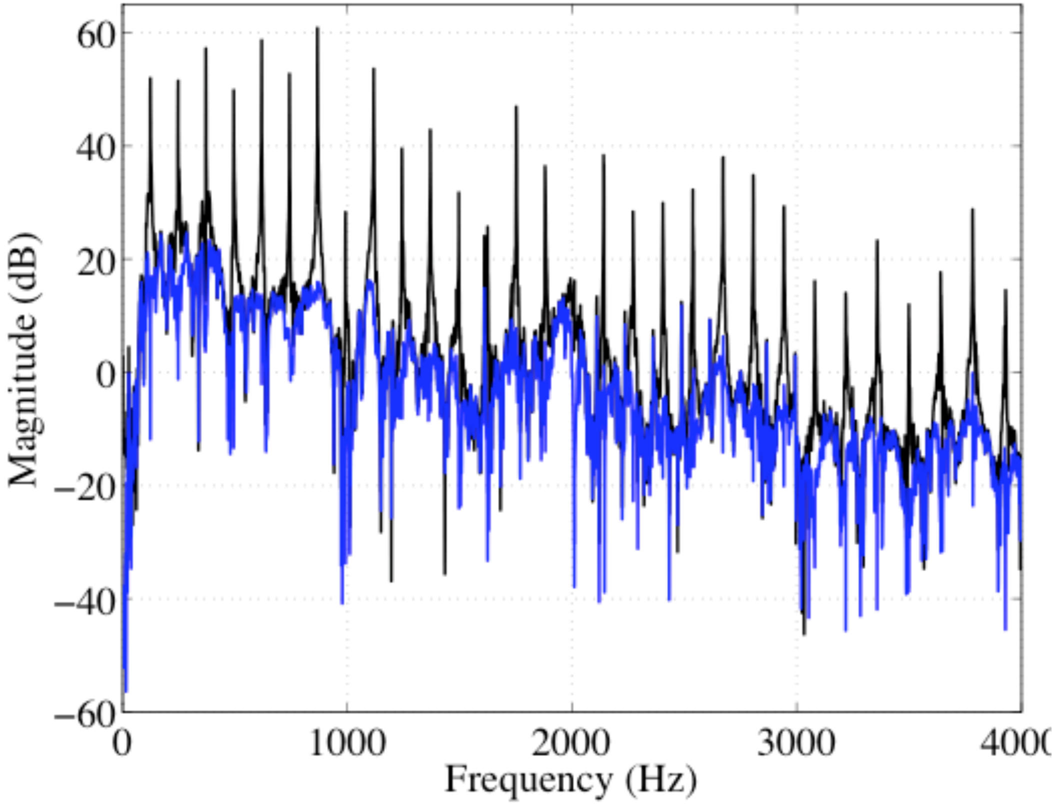
- Use a recorded piano tone D5 (f_0 = 587.1 Hz, B = 0.0012), filter twice for good attenuation
- FIR performs better

x = Attenuation at partial frequencies

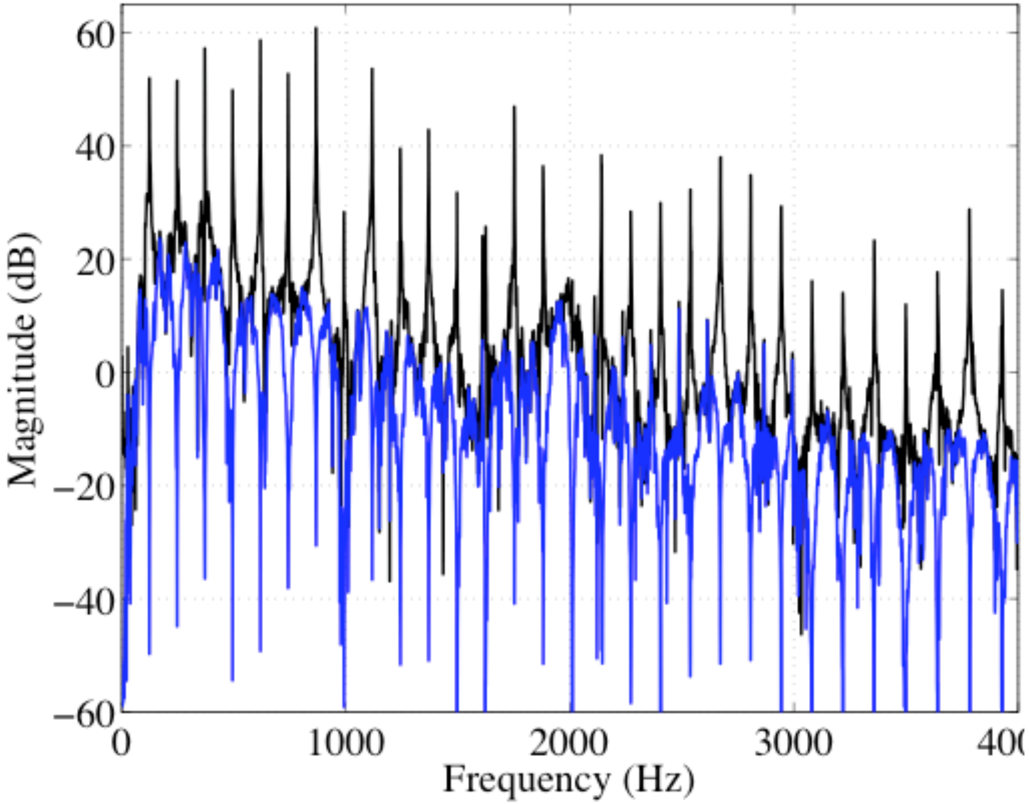


Application #3: Residual Signal Extraction

B2 filtered once



B2 filtered twice



— Original tone — Filtered

Conclusions

- Filtering-based analysis tool for inharmonic musical tones was presented
- FIR filter designed by frequency sampling and an IIR filter by Abel and Smith (DAFx-06) were used to implement frequency-dependent delay in ICF
- Provides a simple and efficient way to cancel and select partials from piano tones

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