Simple Multi Frame Analysis Methods for Estimation of Amplitude Spectral Envelope in Singing Voice

Gilles Degottex, Luc Ardaillon, Axel Roebel

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Ircam - Institut de Recherche Coordination Acoustique/Musique
Paris, France

Problem

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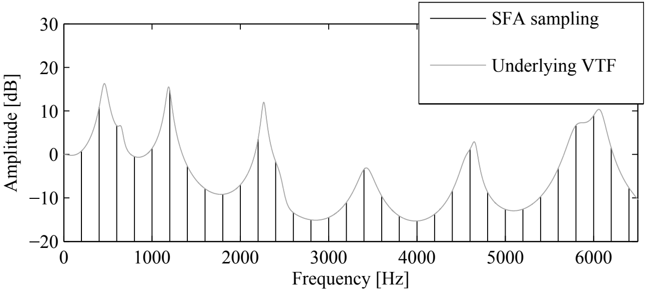

SFA sampling
Underlying VTF
Amplitude [dB]
Frequency [Hz]
30
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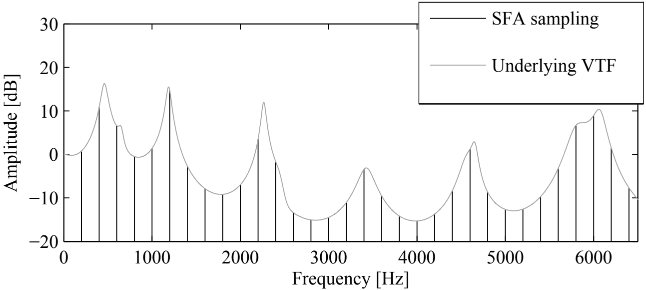

- SFA is enough for reconstructing some shapes, not all of them.

Problem in spectral envelope estimation

Current situation

- A single frame of DFT transform is commonly used.

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- Multiple Frame Analysis (MFA) has already been suggested [1,2].
  Consecutive neighbor frames [2], or non-consecutive among a corpus [1].
  Though, often with excessive complexity and without results used in current applications.

[1] Y. Shiga and S. King "Estimation of voice source and vocal tract characteristics based on multi-frame analysis," *Proc. EUROSPEECH*, 2003.
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We suggest to

- Start with a simple and very controlled context:
  Sustained segments of singing voice with vibrato.

  (stationary VTF, varying f_0: ideal case for MFA!)
- Study very simple MFA-based envelope estimation methods.

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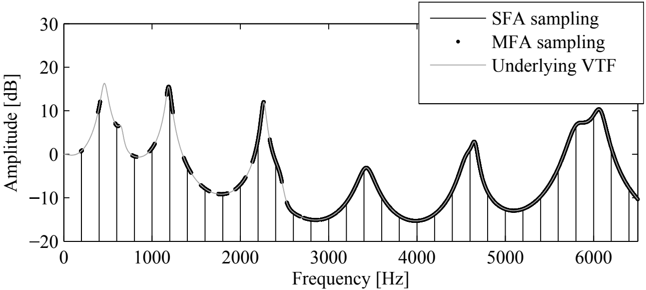

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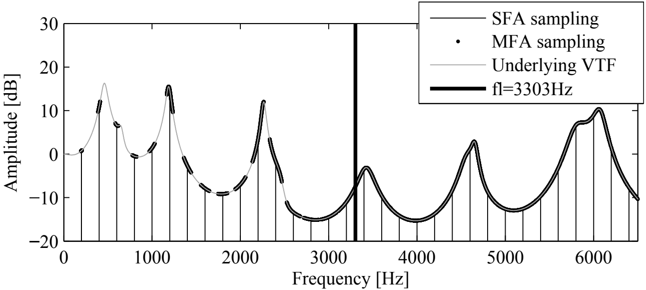

Using a time window of 2 vibrato periods ($\sim$400ms)

- The MFA coverage increases with the harmonic number
- From f_l and above the VTF is fully covered

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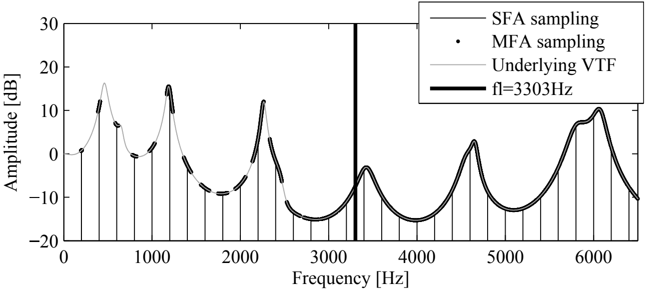

Using a time window of 2 vibrato periods (∼400ms)

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Questions to answer

- How to reconstruct the remaining low frequencies of the envelope?
- Since the source is AM, how to align consecutive frames?

  (first alignment then envelope estimation? joint estimation of alignment and envelope?)

Methods

Method: Simplified Discrete Cepstral Envelope for MFA (SDCE-MFA)

The envelope model is the same as in SFA:

$$E(f) = c_0 + 2\sum_{n=1}^{P} c_n \cos(n2\pi f/f_s) \tag{1}$$

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And the MFA solution suggested by Shiga et al.[2]:

$$\Big(\sum_{k=1}^{K} \mathbf{B}_k^T\mathbf{B}_k\Big)\mathbf{c} = \sum_{k=1}^{K} \mathbf{B}_k^T(\mathbf{a}_k - d_k\mathbf{u}_k) \qquad (MFA) \quad (3)$$

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In this paper, we have shown that the frame alignment d_k impacts only the overall envelope gain, but not its shape.
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Procedure for the SDCE-MFA

1. Compute: $\mathbf{c} = \sum_{k=1}^{K} \left(\sum_{l=1}^{K} \mathbf{B}_l^T \mathbf{B}_l \right)^{-1} \cdot \left(\mathbf{B}_k^T \mathbf{a}_k \right)$
2. Align the resulting shape on the peaks of the central frame

Method: MFA Linear interp. + Cepstral liftering (Linear-MFA-LIFT)

Procedure for the Linear-MFA

1. Align the frames using the energy
2. Linear interpolation of all the peaks among all frames (used in [1])

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Procedure for the Linear-MFA-LIFT

1. Align the frames using the energy
2. Linear interpolation of all the peaks among all frames (used in [1])
3. Low-pass lifter the result according to a cepstral order P

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Evaluation

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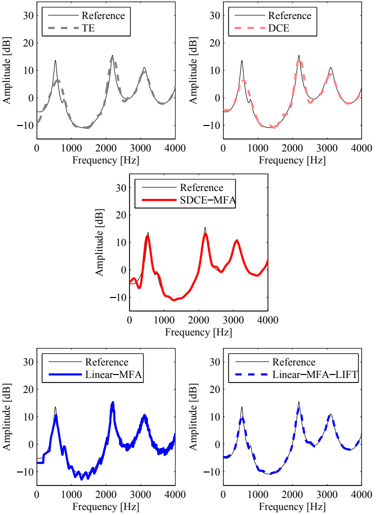
Evaluation: Methods compared



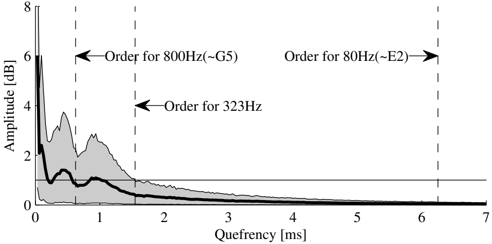
SFA

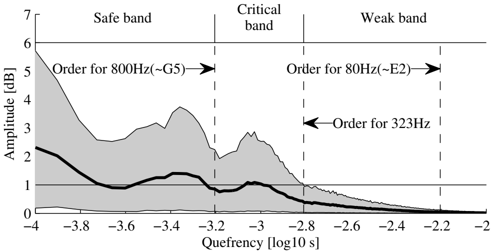
- "True-Envelope" (TE)
  Also cepstral model, iterative solution
- Discrete Cepstral Envelope (DCE)
  LS solution + regularization

MFA

- SDCE-MFA
  LS solution
- Linear-MFA-LIFT
  Liftered linear interpolation

Evaluation: Quefrency bands





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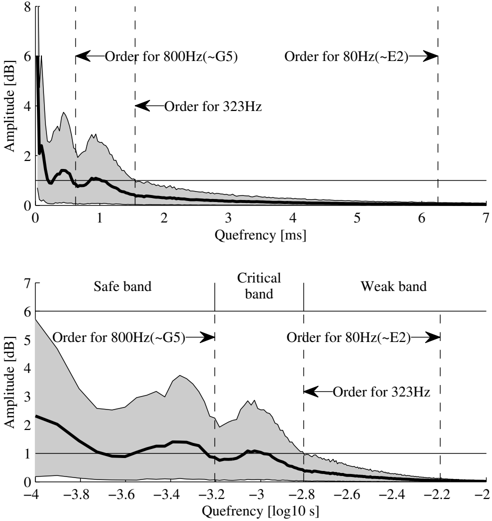

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- Assuming $f_0 \in [80, 800]$Hz
- Usual order for cepstral models: $\mathrm{P} = \frac{0.5 f_s}{f_0}$

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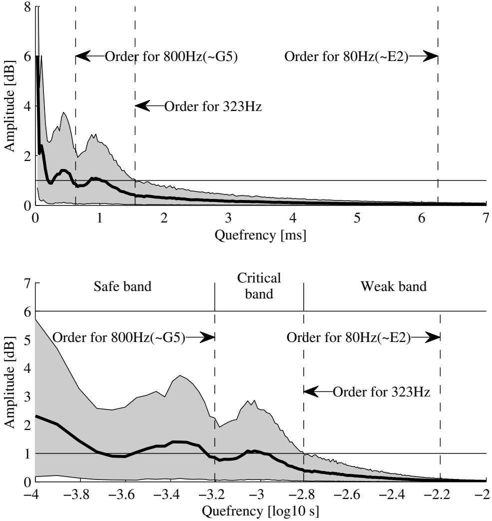

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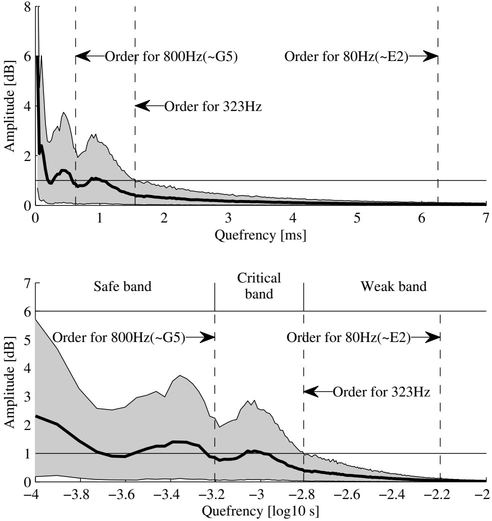

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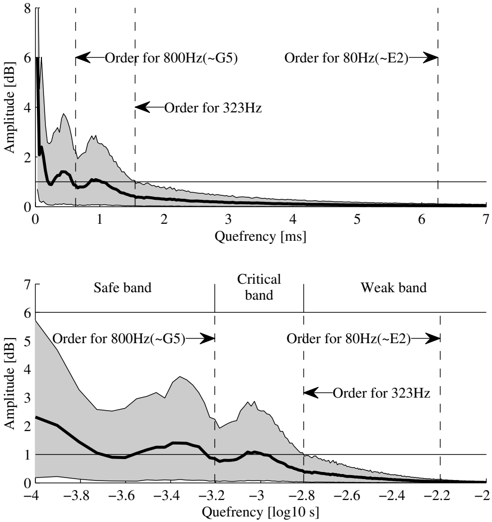

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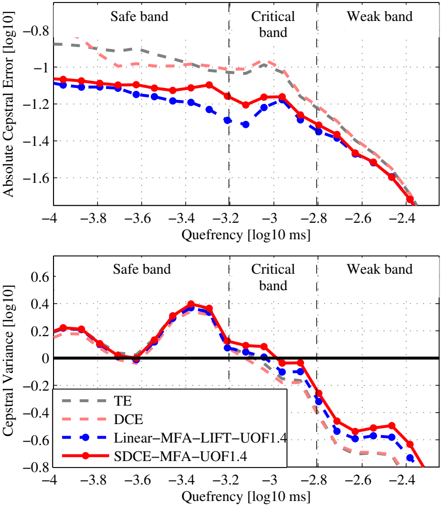
- **Weak band**: From auditory threshold to inf
- **Safe cepstral band**: Zero to minimum order
- **Critical band**: From minimum order to auditory threshold of 1dB

Evaluation: Numerical evaluation using synthetic signals



Experimental data

- 1000 samples of 2s
- $f_0 \in [80, 800]$Hz
- Vibrato extent $\in [0, 150]$cents
- Vibrato freq $\in [4, 6]$Hz
- Source Dirac impulse
- Random AM of std$= 0.5$dB
- Convolved by a random VTF

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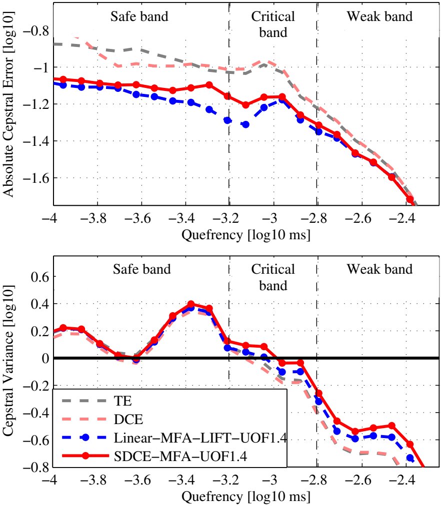

Estimation setup

- Window length for MFA:
  2 periods of vibrato $\Rightarrow \sim$400ms
- We take advantage of the MFA by *boosting* the cepstral order:
  $P = 1.4 \cdot \frac{0.5 f_s}{f_0}$

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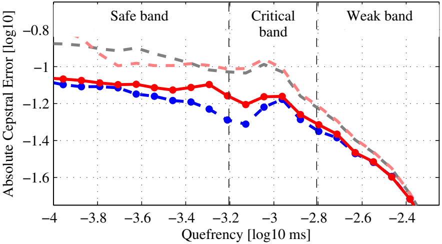

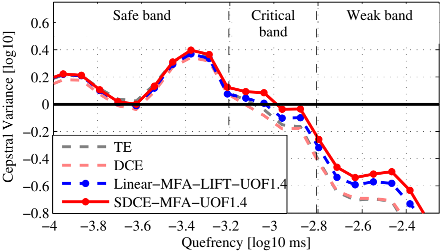

Absolute cepstral error:

$$\epsilon_{n,i} = \frac{1}{M} \sum_{m=1}^{M} \left| c^*_{n,i} - c_{m,n,i} \right| \qquad (4)$$

$c^*_{n,i}$ the reference sample i; M the number of frames in i

Cepstral Variance:

$$\bar{\sigma}_n = \frac{\mathrm{std}_i(\bar{c}_{n,i})}{\mathrm{std}_i(\bar{c}^*_{n,i})} \quad \bar{c}_{n,i} = \frac{1}{M} \sum_{m=1}^{M} c_{m,n,i} \qquad (5)$$

$\bar{c}_{n,i}$ the average cepstrum over M; $\mathrm{std}_i(.)$ the standard-deviation over i

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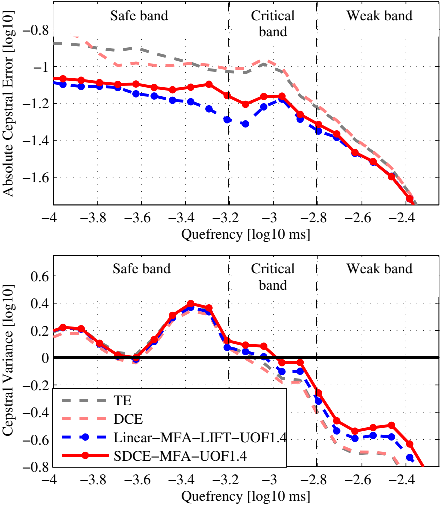

Results

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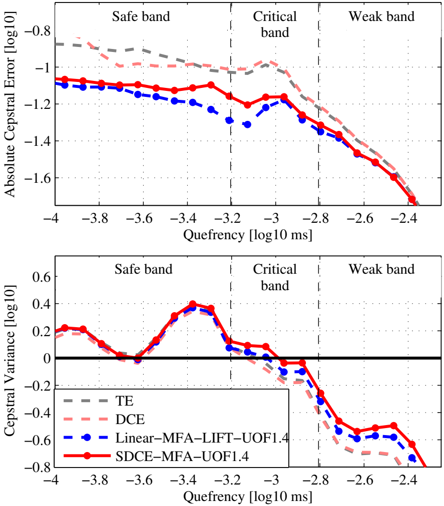

Results

- In safe band: MFA almost divides the error by 2
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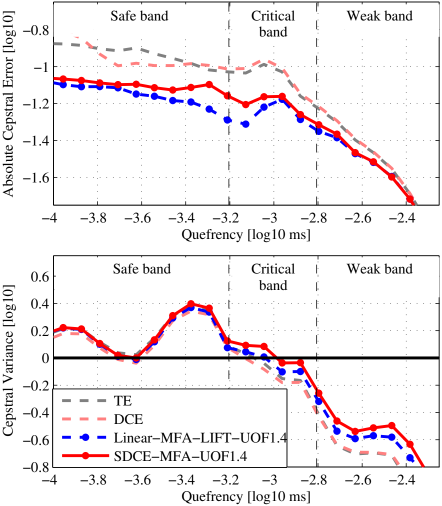

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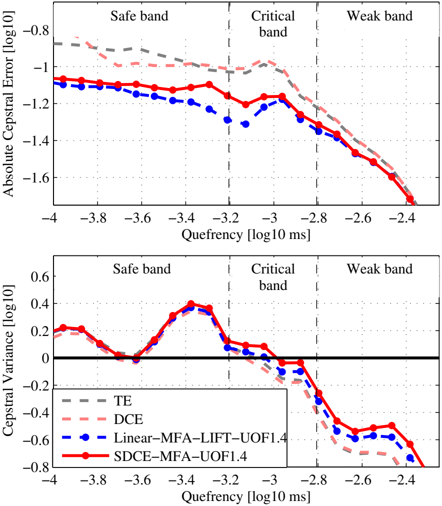

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  Averaging effect!
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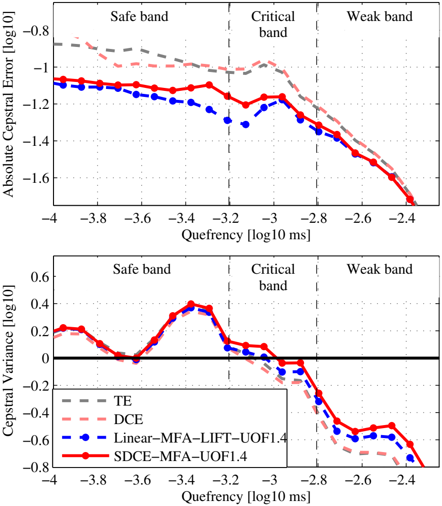

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  Averaging effect!
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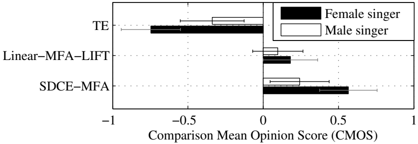
- MFA methods better recover the variance

Evaluation: Listening tests about pitch scaling



Experimental setup

- 2 voices (female and male) (proof of concept!)
- 15 sustained French vowels + natural vibrato
- Up and down pitch scaling (x0.75, x1.25)
- Dropped DCE-SFA to keep test duration low
- Each listener assessed 4 random vowels
- Web-based sent to mailing-lists

Samples accessible at:

`http://gillesdegottex.eu/Demos/DegottexG2016mfaenvsing/`

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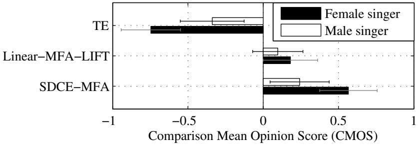

Results (31 listeners)

- MFA methods clearly preferred
- Linear-MFA-LIFT very good improvement

  (and very efficient computationally!)
- SDCE-MFA shows better improvement for the female voice

  (might be due to the better variance reconstruction)

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Conclusions: Points worth remembering

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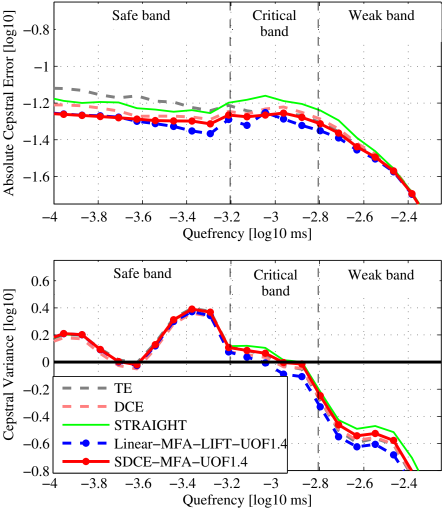
Journal article just accepted!

G. Degottex, L. Ardaillon, A. Roebel "Multi-Frame Amplitude Envelope Estimation for Modification of Singing Voice", *IEEE TASLP*, accepted 2016.

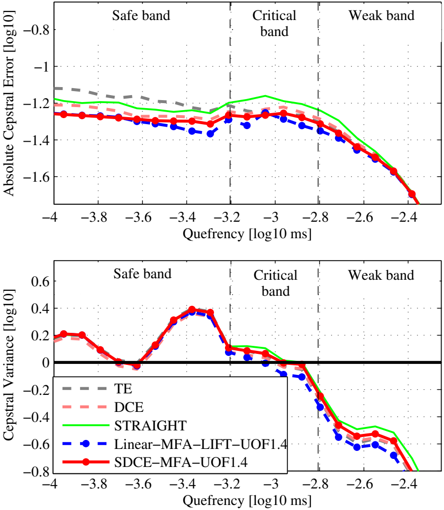
感謝您的關注
Gracias por su atención
Thank you for your attention
आप अपना ध्यान के लिए धन्यवाद
شكرا لكم على اهتمامكم
Obrigado pela sua atenção
Спасибо за ваше внимание
ご清聴ありがとう
మీ శ్రద్ధకు ధన్యవాదాలు
Je vous remercie de votre attention
Σας ευχαριστώ για την προσοχή σας
Dankon pro via atento
please no question about the window

Evaluation: Numerical evaluation using synthetic signals



What about speech?

Evaluation: Numerical evaluation using synthetic signals



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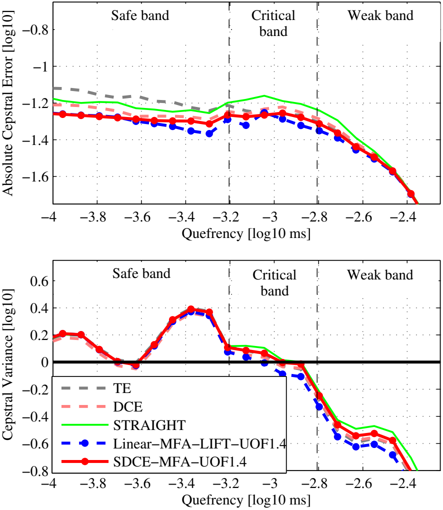

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  $\Rightarrow$ Less disparities of errors

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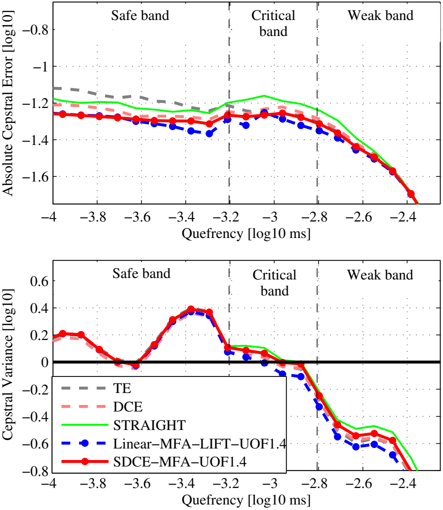

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  $\Rightarrow$ Variance of SFA similar to MFA

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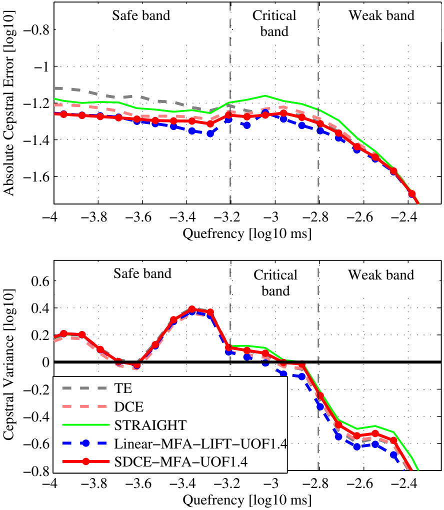

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  $\Rightarrow$ Variance of SFA similar to MFA
- For MFA we need:

  $$\frac{\mathrm{var}(\mathrm{VTF})}{\mathrm{var}(f_0)} \text{ as small as possible}$$

  Small enough for speech?
  Doesn't seem to be the case :(