Noise Removing for Time-Variant Vocal Signal by Generalized Modulation

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Outline

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1. Introduction

- Noise removal: An essential issue for vocal signal processing.

- Well-known techniques: Spectral subtraction methods, Wiener filtering, etc.

- However, **none of** these methods consider that the spectrum of a vocal signal may vary with time.

- Neither do they utilize **the time and the frequency domain** characteristics **simultaneously** to design the filter.

1. Introduction

- In order to take into account the varying instantaneous frequency, we exploit the **time-frequency analysis** by using the **short time Fourier transform(STFT):**

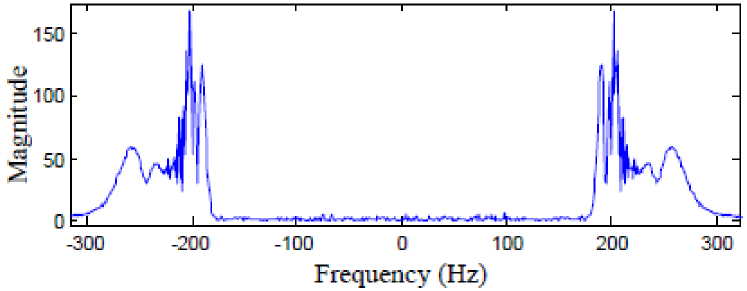


Figure. The FFT of a human vocal signal

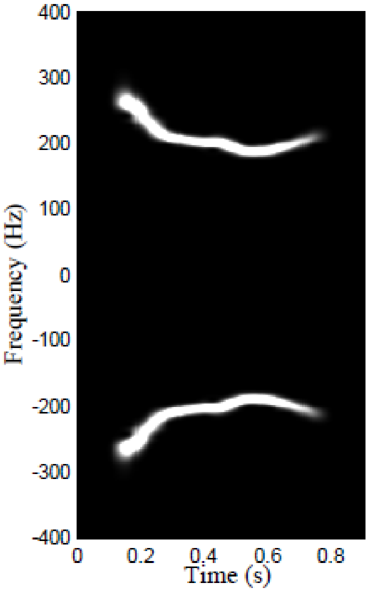


Figure. The STFT of the same signal

1. Introduction

- Basically, a simple way to remove noise is by using frequency selective filters; e.g., a lowpass filter. However, a great deal of noise might still remain if the signal bandwidth is large.

- Therefore, we try to find out the method to further reduce noise by modifying the signal into one with a **narrower bandwidth** before going to the lowpass filtering step.

1. Introduction

- The flowchart of our noise-removing algorithm.

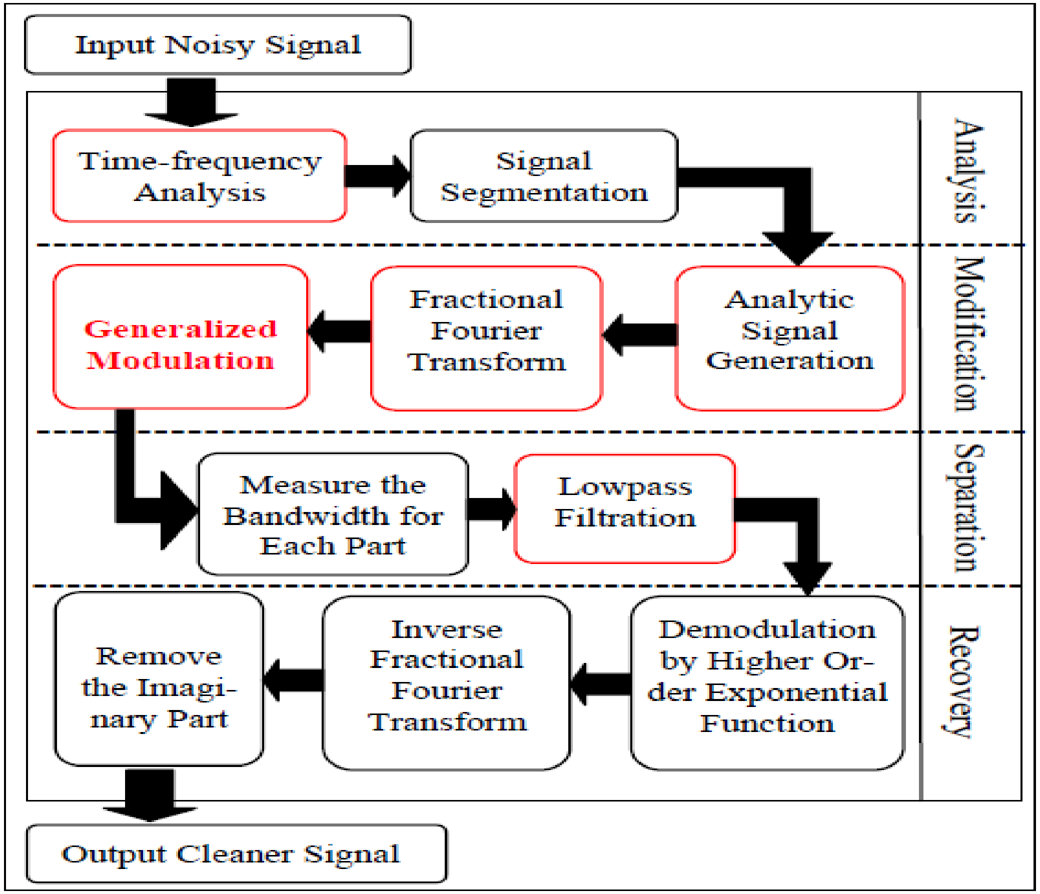
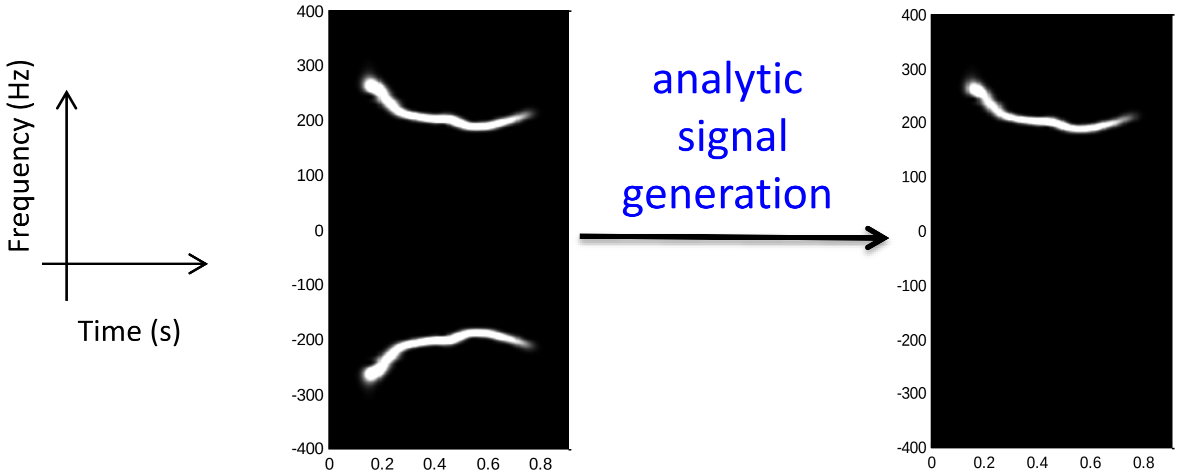


Figure. Flowchart of the proposed noise-removing algorithm.

2. Conventional Modulation Method

- **Analytic signal generation**
  - the analytic signal generation is to halve the signal bandwidth
  - the negative part of a signal will be removed and the positive part will remain

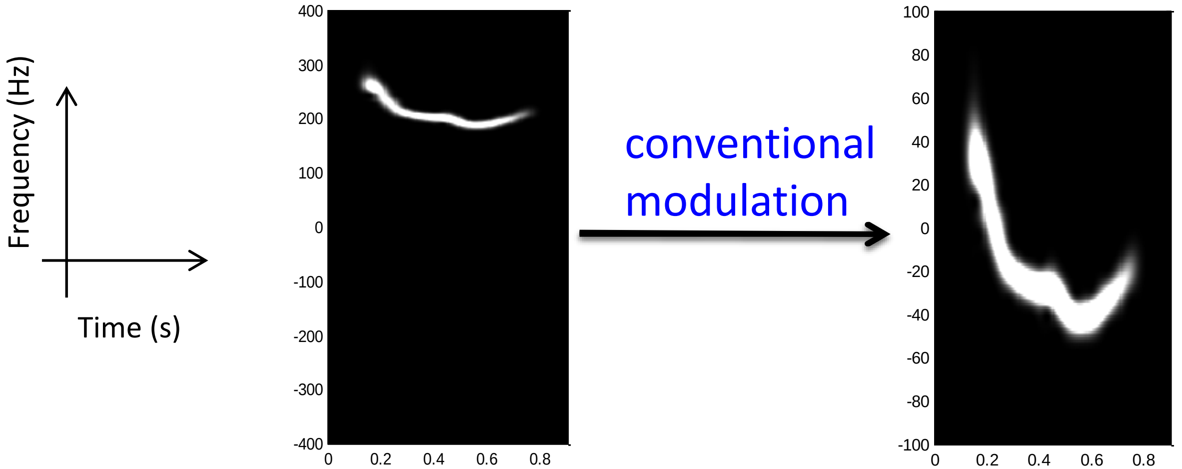


2. Conventional Modulation Method

- **Conventional modulation**
  - a modulation function $m_c(t)$ is an exponential function with the first order phase:

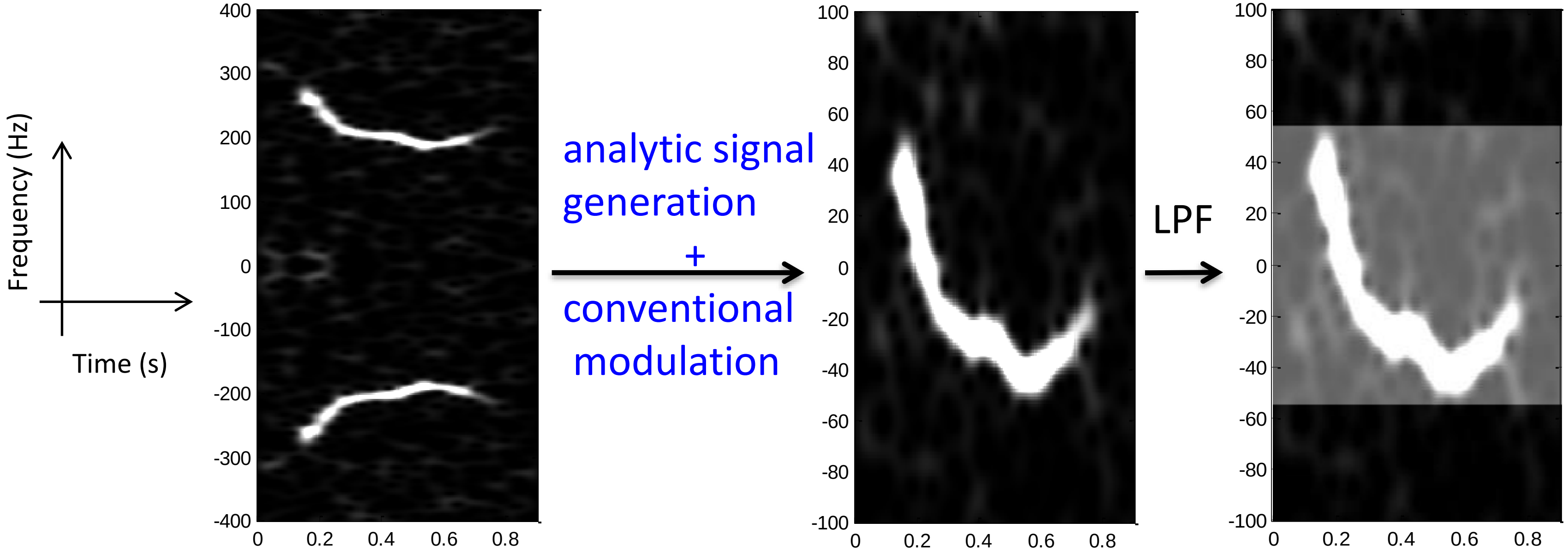
$$m_c(t) = \exp(-j2\pi f_1 t)$$

  - by **multiplying** $m_c(t)$, the signal will be frequency-shifted by f_1 Hz in the frequency domain.



2. Conventional Modulation Method

- **Apply to the noisy signal**

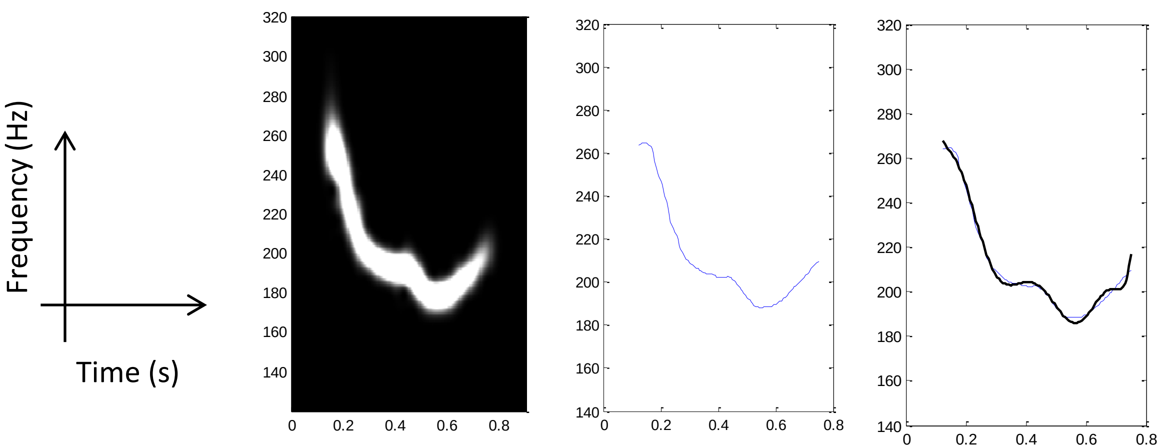


3. Proposed Generalized Modulation

- **Generalized modulation**
  - Instead of multiplying a first order exponential function, the modulation function of generalized modulation $m_g(t)$ is an exponential function with a higher order polynomial:

$$m_g(t) = \exp[-j2\pi(a_n t^n + a_{n-1}t^{n-1} + \cdots\cdots + a_1 t + a_0)]$$

  - The polynomial is derived by approaching the central frequency of the signal



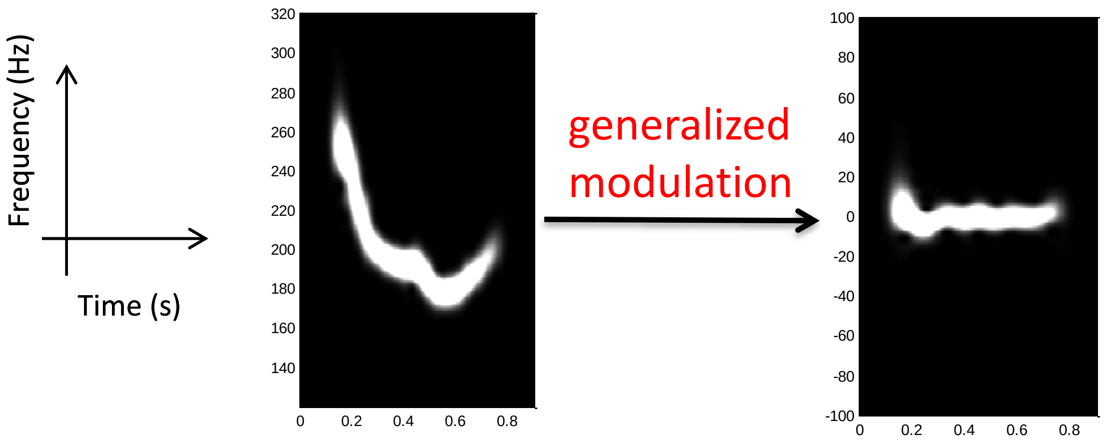
Blue line: the central frequency of the signal
Black line: the approaching polynomial

3. Proposed Generalized Modulation

- **Generalized modulation**
  - by **multiplying** $m_g(t)$, the instantaneous frequency of the signal will be shifted by $f_{in}\ (t)$Hz, where

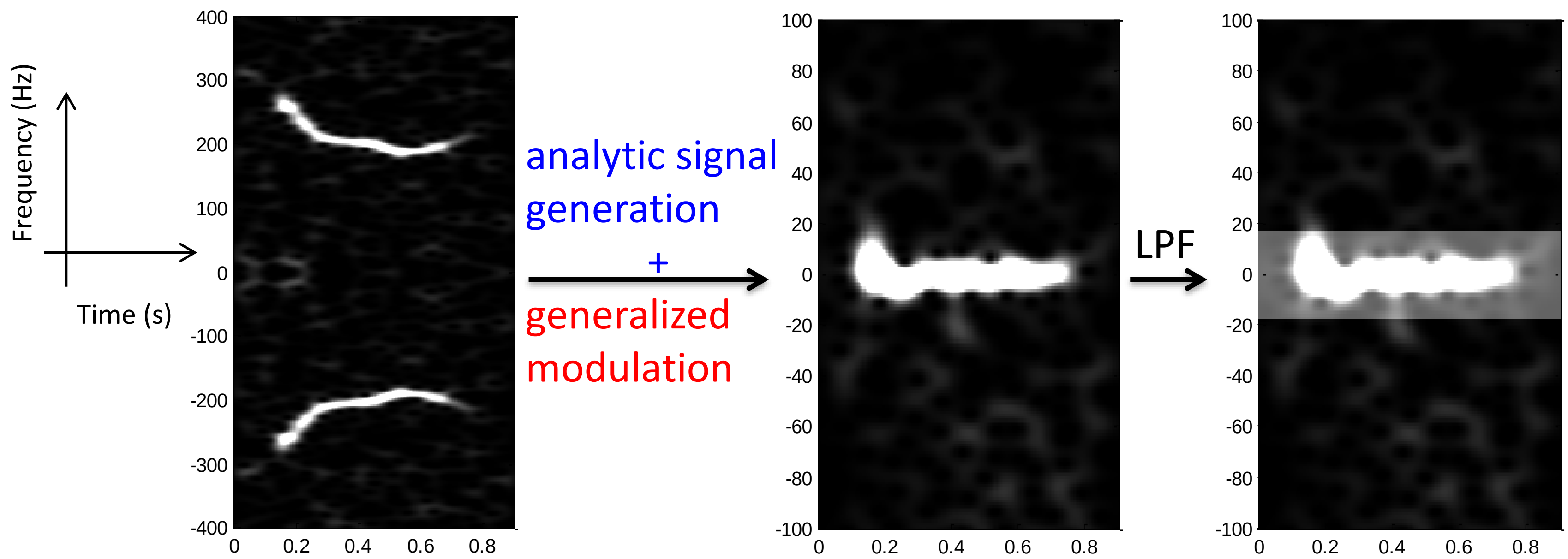
$$f_{in}(t) = \frac{1}{2\pi}\frac{d}{dt}\arg\left(m_g(t)\right) = \frac{d}{dt}[-(a_n t^n + a_{n-1}t^{n-1} + \cdots\cdots + a_1 t + a_0)]$$

$$= -[na_n t^{n-1} + (n-1)a_{n-1}t^{n-2} + \cdots\cdots + a_1]$$



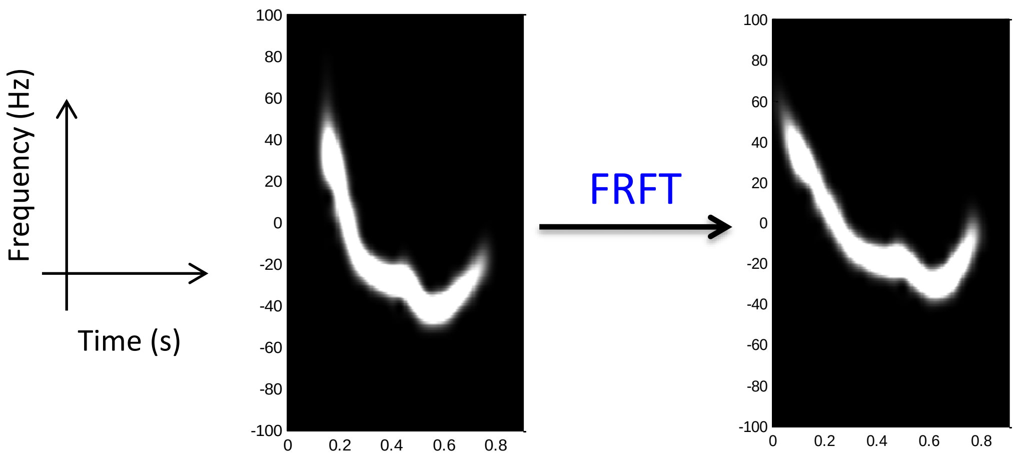
3. Proposed Generalized Modulation

- **Apply to the noisy signal**



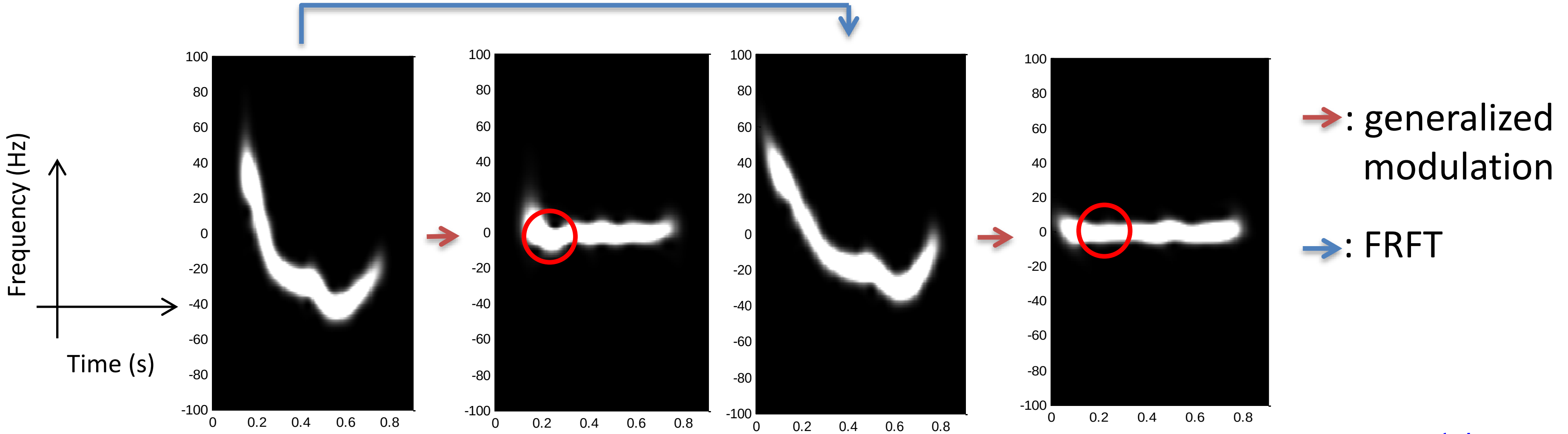
4. Combining the Fractional Fourier Transform

- **Fractional Fourier Transform (FRFT)**
  - we find that, **combining** the proposed generalized modulation **with the FRFT**, a very narrow signal bandwidth can be achieved.
  - The FRFT assists the generalized modulation in reducing the signal bandwidth by “rotating” the time-frequency distribution in advance.



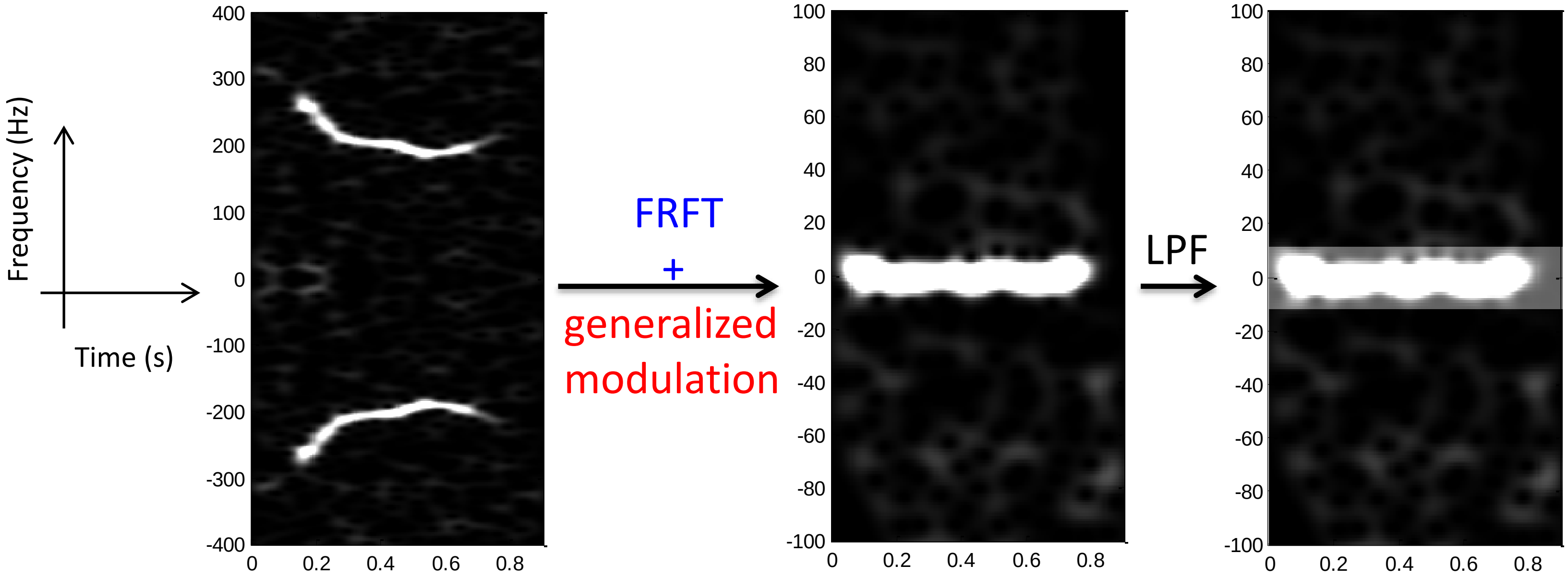
4. Combining the Fractional Fourier Transform

- **Fractional Fourier Transform (FRFT)**
  - Note that, for the human vocal signal, it has **very large negative slope** around **0.2 second**, which causes the modulated signal to be **out-of-flatness** around 0.2 second. However, if we rotate the time-frequency distribution of the signal in advance, we can alleviate the effect of large slope on the modulated signal



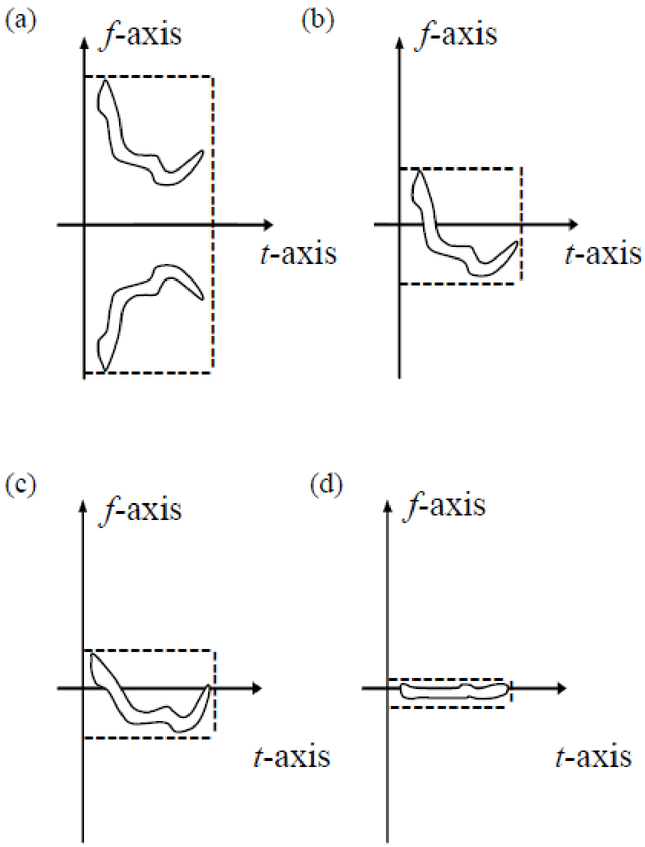
4. Combining the Fractional Fourier Transform

- **Apply to the noisy signal**



4. Combining the Fractional Fourier Transform

- **The proposed noise-removing algorithm**



(a) The original signal.
(b) Analytic signal conversion + conventional modulation.
(c) Analytic signal conversion + FRFT + conventional modulation.
(d) Analytic signal conversion + FRFT + proposed generalized modulation.

5. Simulation Results

- We totally experiment on 4 different time-variant audio signals: 3 human vocal signals and 1 whale voice signal.

- We add the AWGN with different average powers to the signals to see the performances of different noise-removing schemes under various noise conditions.

- The noise reduction performances are measured by the NMSE (Normalized Mean Square Error).

5. Simulation Results

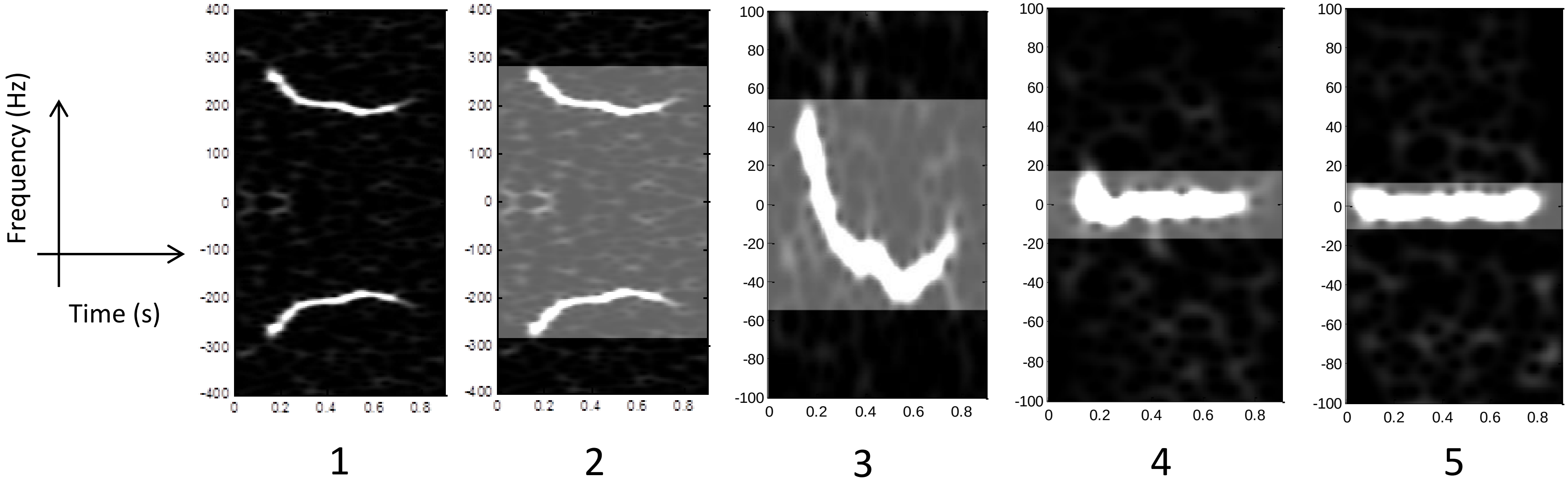
- In each experiment, we compare the following 5 different noise-removing schemes:

1. **Original Error**
   -the noisy signal without any modifications
2. **LPF:**
   -the noisy signal after a proper lowpass filter
3. **Analytic + Conventional Modulation + LPF**
   -the noisy signal modified by the noise-removing scheme based on the conventional modulation
4. **Analytic + Proposed Generalized Modulation + LPF**
   -the noisy signal modified by the noise-removing algorithm based on the proposed generalized modulation
5. **Analytic + FRFT + Proposed Generalized Modulation + LPF (Proposed Algorithm)**
   -the noisy signal modified by the proposed noise-removing algorithm

5. Simulation Results

-The human vocal signal-

1. Original Error
2. LPF
3. Analytic + Conventional Modulation + LPF
4. Analytic + Proposed Generalized Modulation + LPF
5. Analytic + FRFT + Proposed Generalized Modulation + LPF **(Proposed Algorithm)**



5. Simulation Results

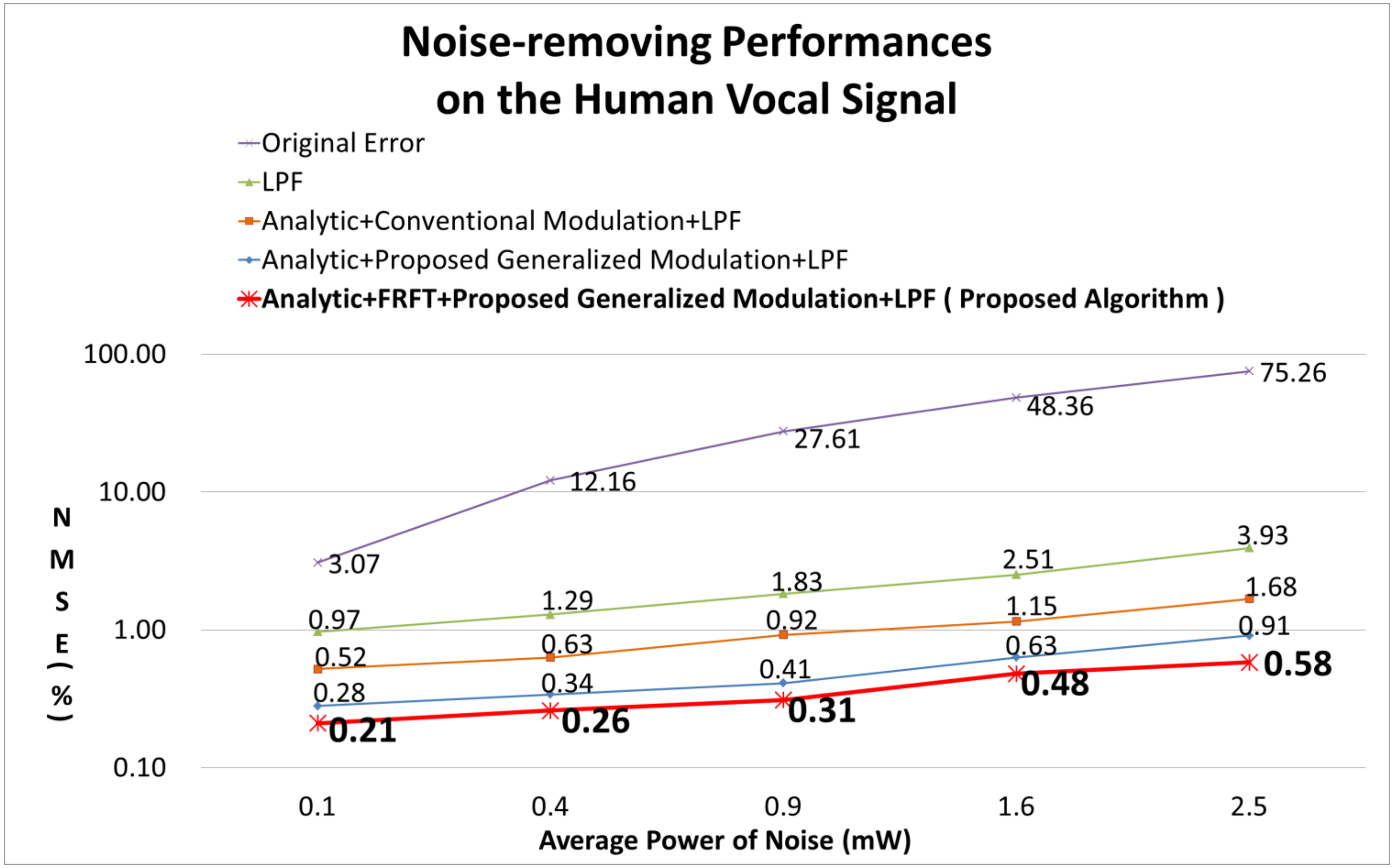
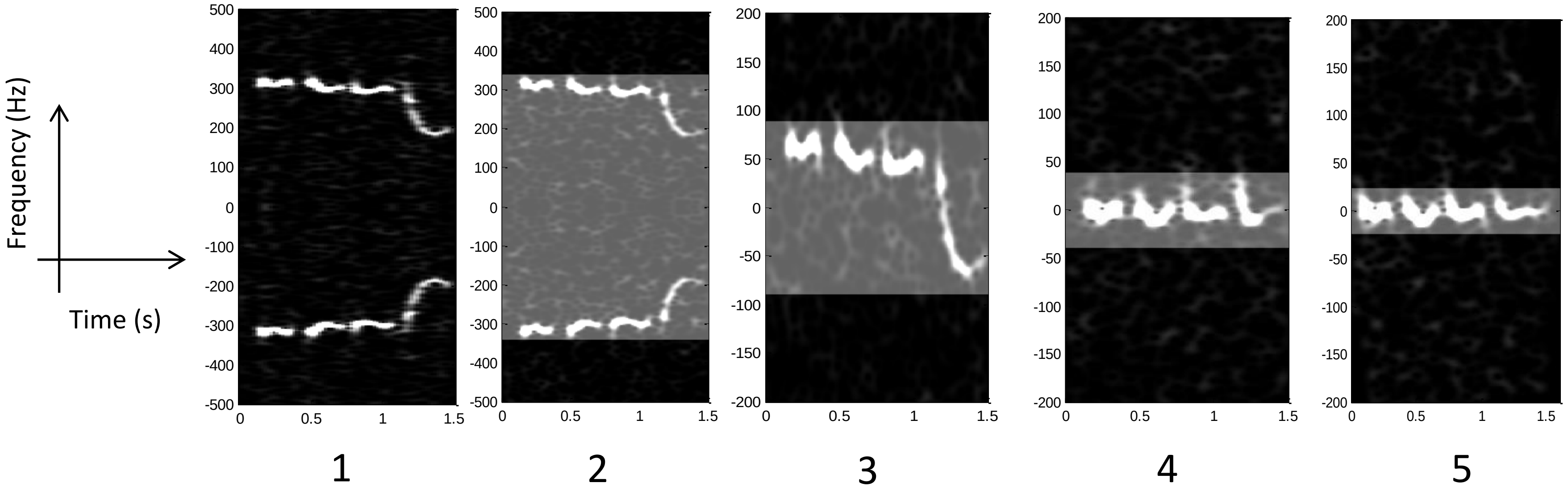


Figure. Comparison among the performances of different noise-removing schemes on the human vocal signal.

5. Simulation Results

-Human Vocal Signal 2-

1. Original Error
2. LPF
3. Analytic + Conventional Modulation + LPF
4. Analytic + Proposed Generalized Modulation + LPF
5. Analytic + FRFT + Proposed Generalized Modulation + LPF **(Proposed Algorithm)**



5. Simulation Results

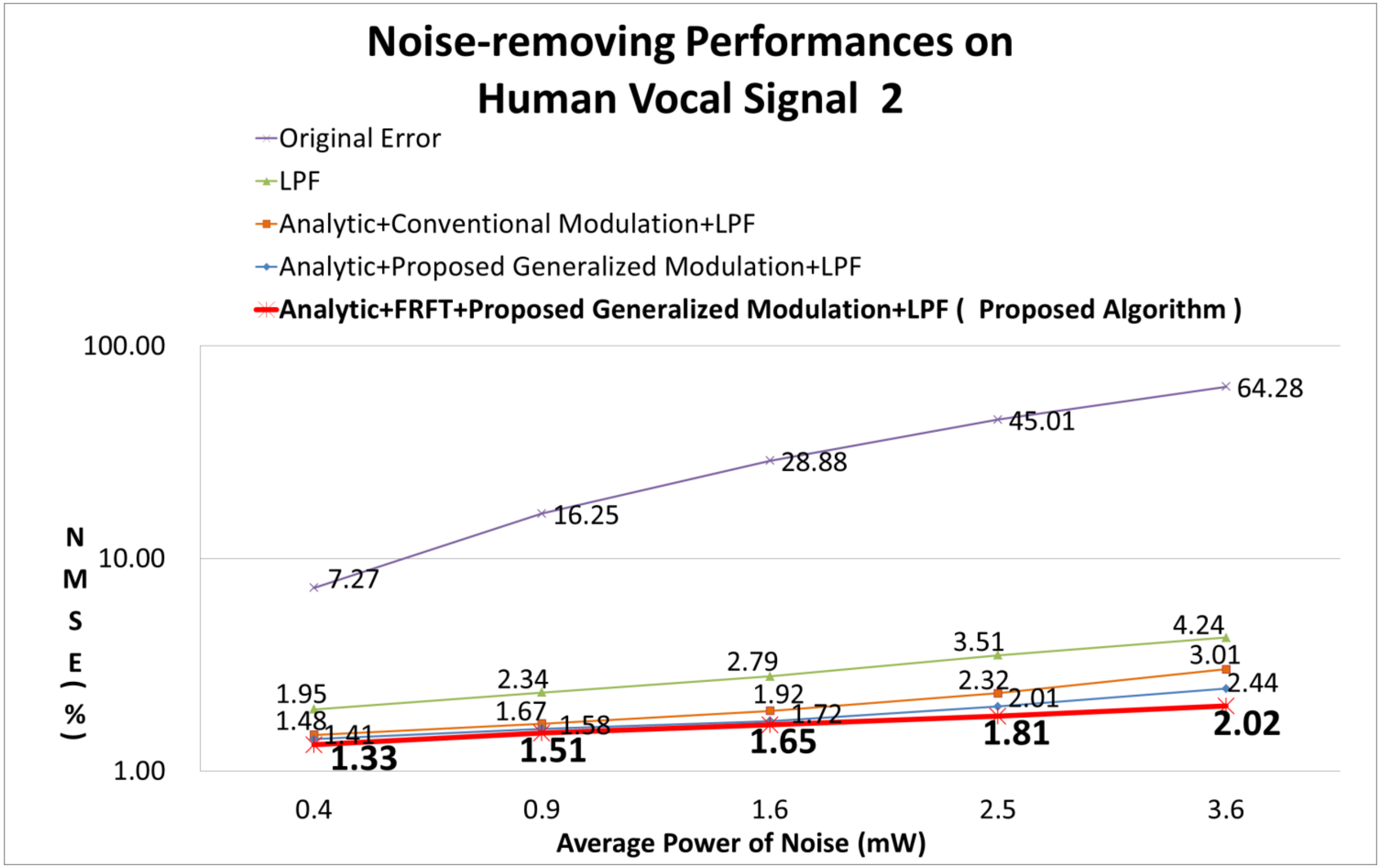
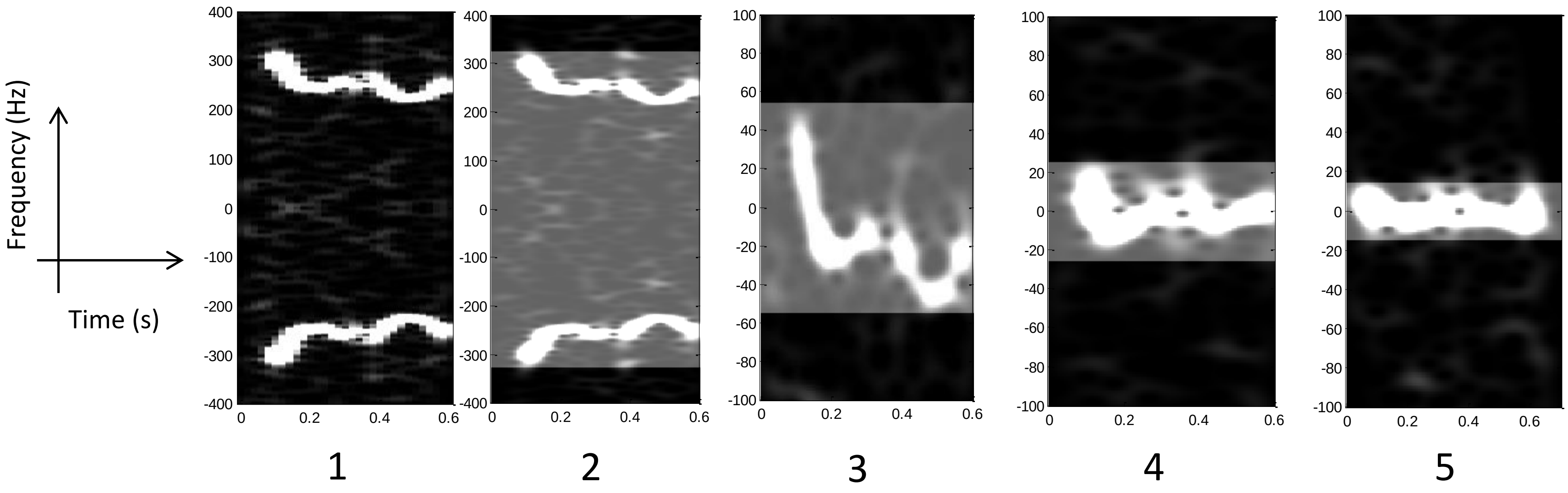


Figure. Comparison among the performances of different noise-removing schemes on Human Vocal Signal 2.

5. Simulation Results

-Human Vocal Signal 3-

1. Original Error
2. LPF
3. Analytic + Conventional Modulation + LPF
4. Analytic + Proposed Generalized Modulation + LPF
5. Analytic + FRFT + Proposed Generalized Modulation + LPF **(Proposed Algorithm)**



5. Simulation Results

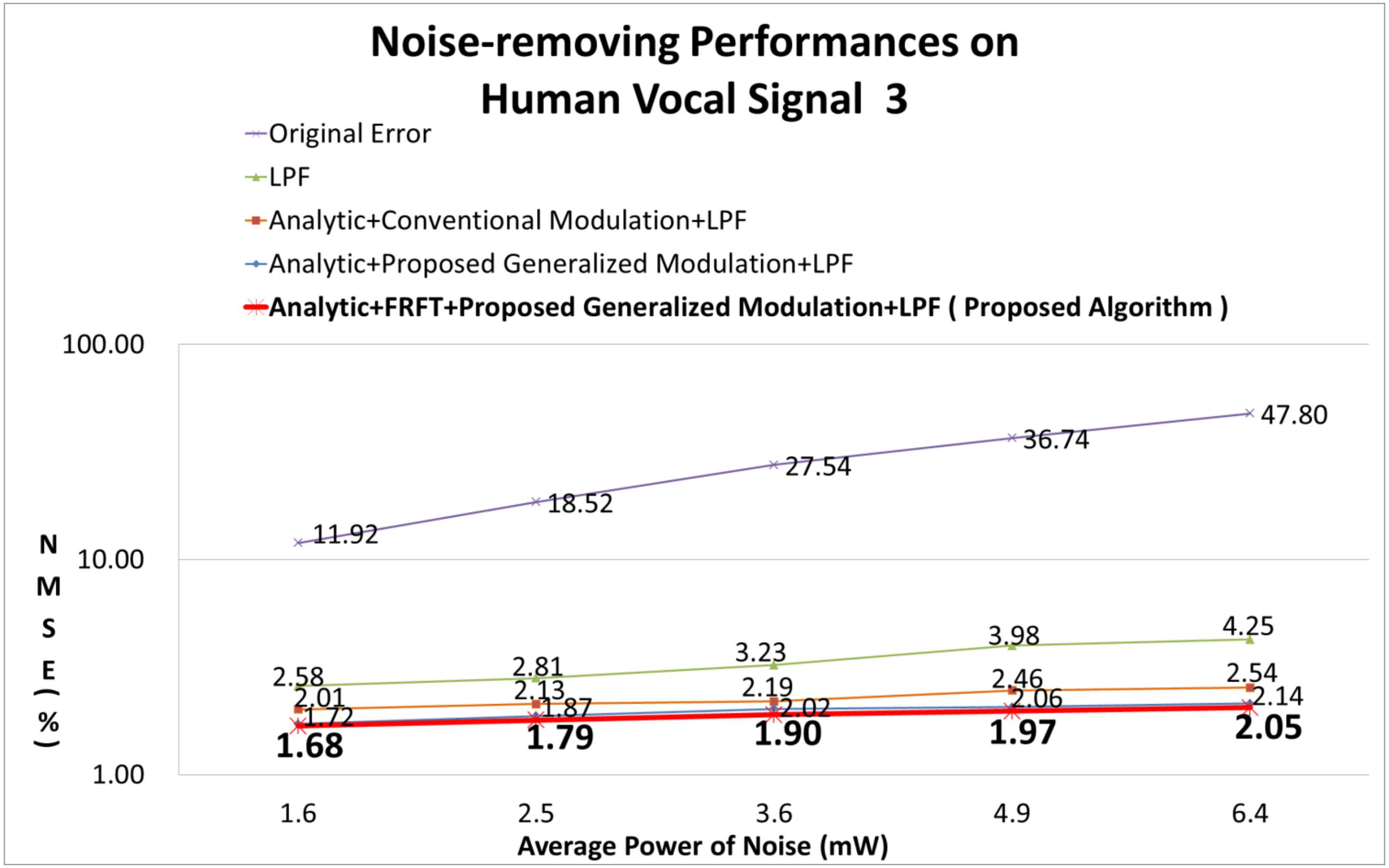
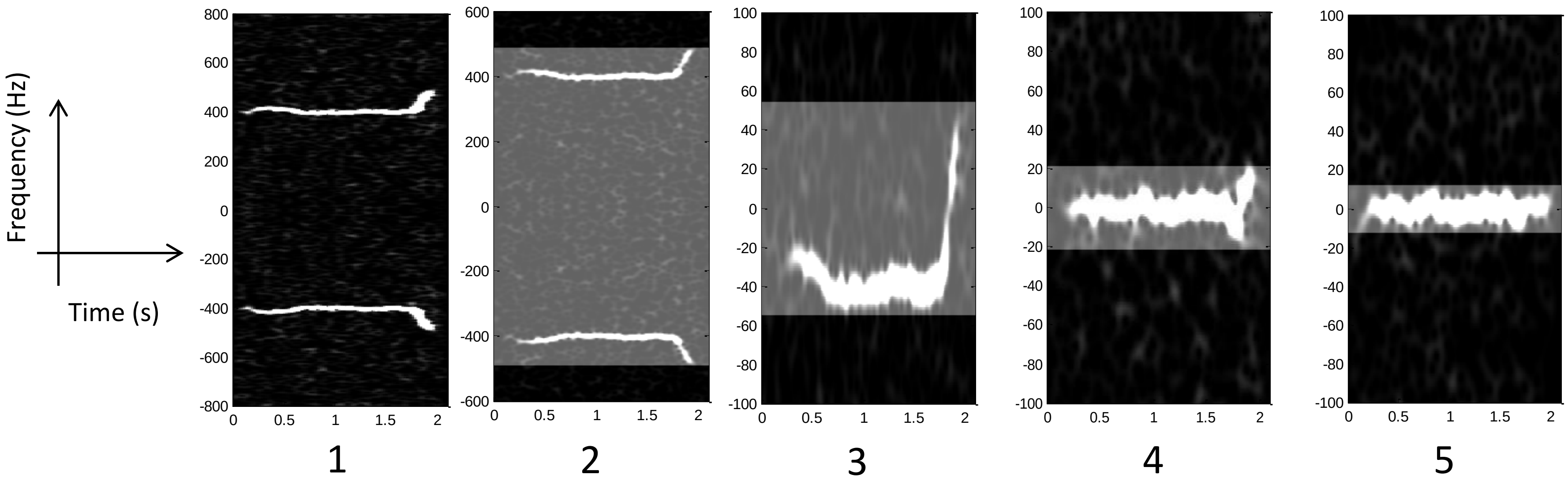


Figure. Comparison among the performances of different noise-removing schemes on Human Vocal Signal 3.

5. Simulation Results

-A whale voice signal-

1. Original Error
2. LPF
3. Analytic + Conventional Modulation + LPF
4. Analytic + Proposed Generalized Modulation + LPF
5. Analytic + FRFT + Proposed Generalized Modulation + LPF **(Proposed Algorithm)**



5. Simulation Results

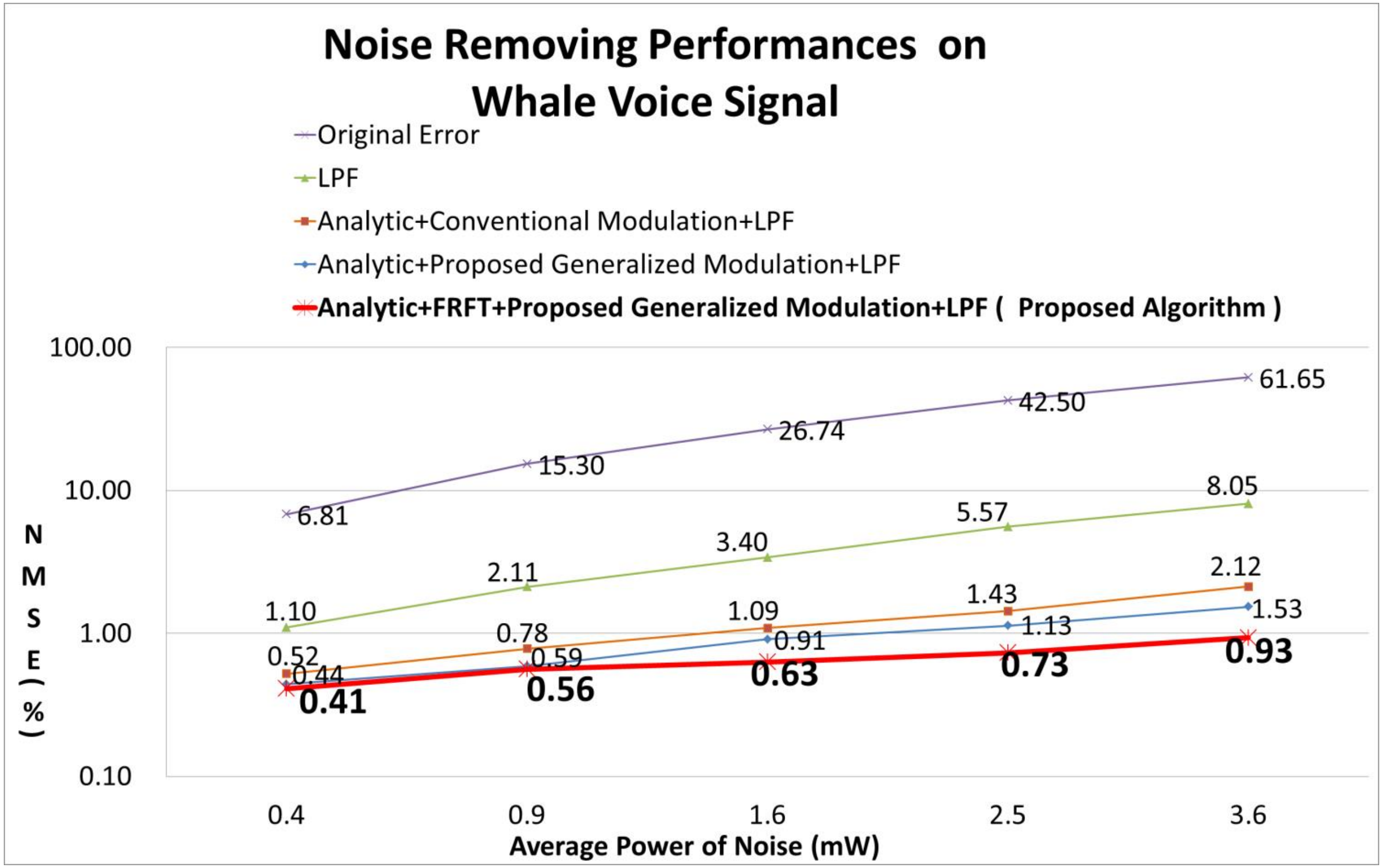


Figure. Comparison among the performances of different noise-removing schemes on a whale voice signal.

6. Conclusions

1. A new noise-removing algorithm is proposed, which is the combination of the STFT, analytic signal conversion, the FRFT filter, and the proposed **generalized modulation** operation.

2. With the proposed algorithm, the area of the signal spectrogram is **reshaped** and the **bandwidth** of the signal is further **minimized**.

3. The signal part and the noise part of a time-variant signal are then well separated and a better noise-reducing performance can be achieved.

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Thanks for your attention.