Modulation Spectral Filtering:
A New Tool for Acoustic Signal Analysis

Prof. Les Atlas

atlas@ee.washington.edu

Department of Electrical Engineering
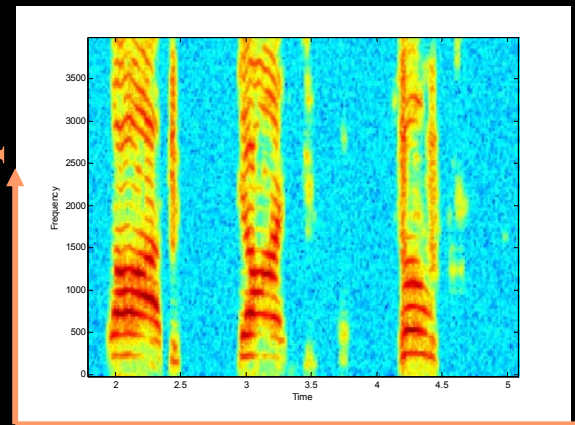
University of Washington

ELECTRICAL ENGINEERING
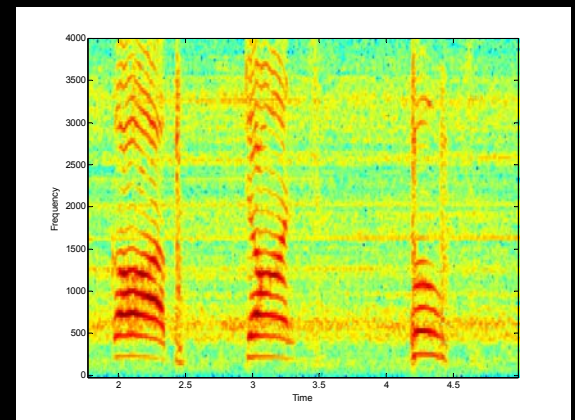**@ *University of Washington***

3-8 Hz Bandpass Modulation Filtered Noisy Speech

Original

Filtered

Modulation Frequency
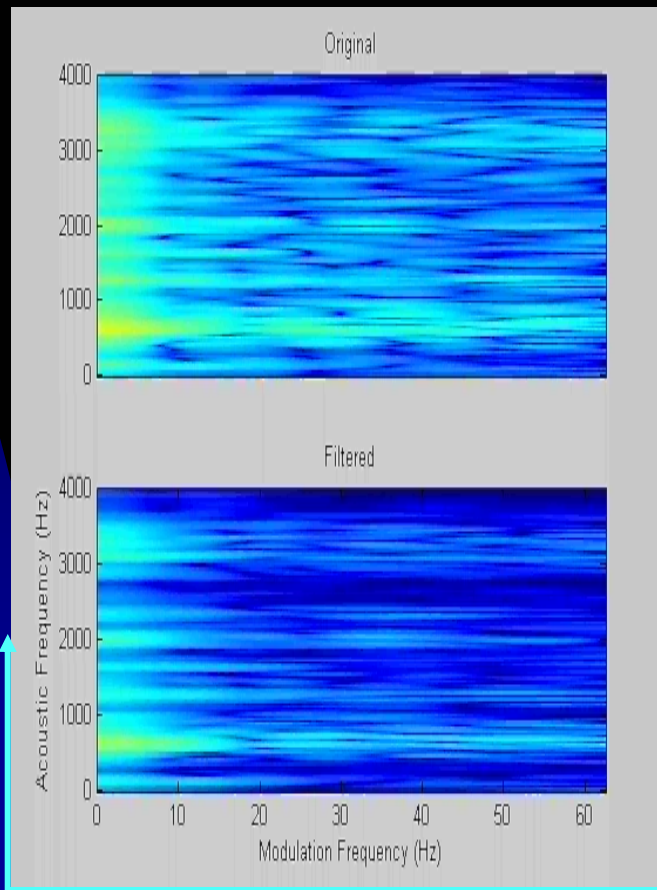
Time
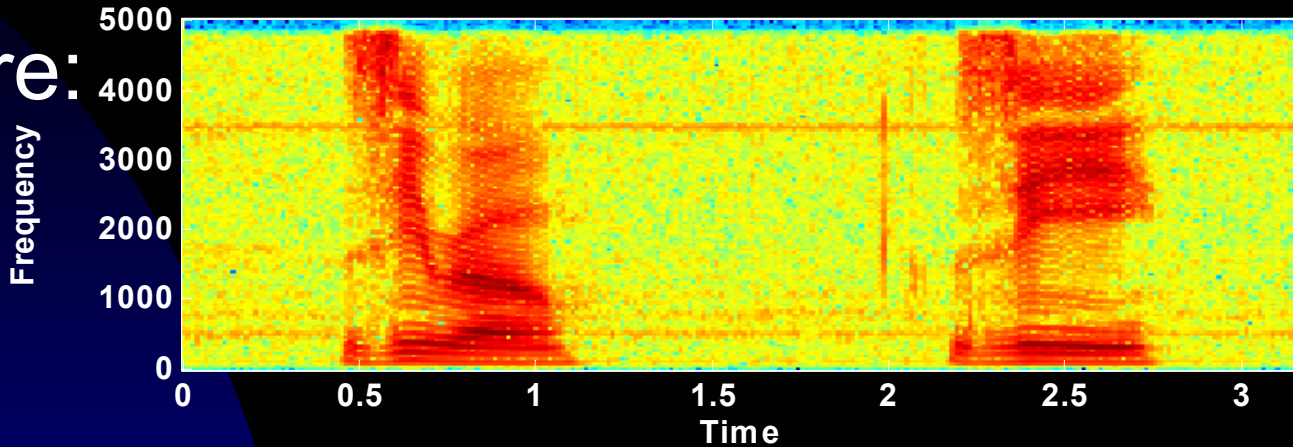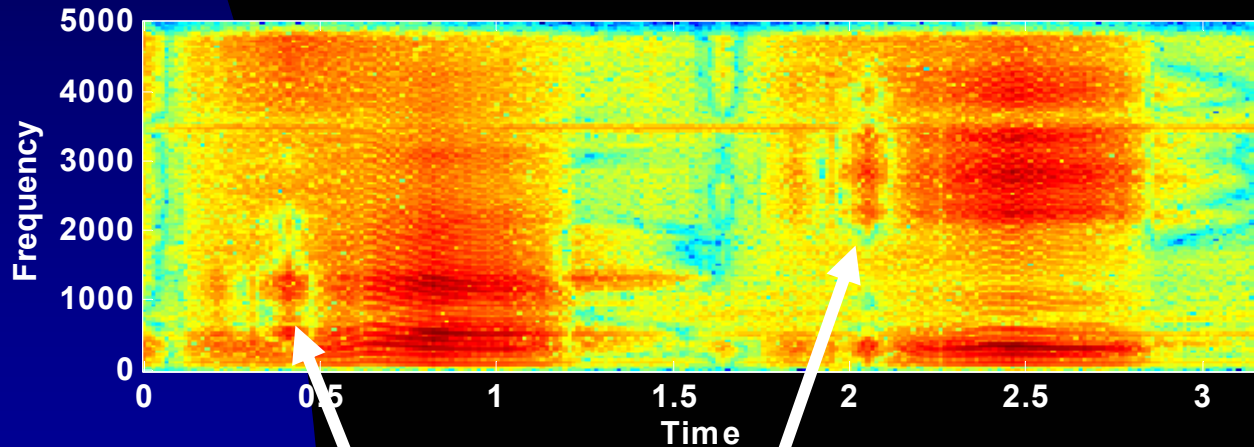
Acoustic Freq

Acoustic Freq

Severe Lowpass Filtering in Modulation

Before:

After:

"Negative magnitude" artifacts

# Recent Insights

- Proven in: Atlas, Li, and Thompson, "Homomorphic Modulation Spectra," *Proc. ICASSP 2004*:

  - Contrary to what has been assumed for at least the last 50 years, a correct model of a modulation envelope is complex and not real and positive.

    - Example: Harmonic not centered in a sub-band.->

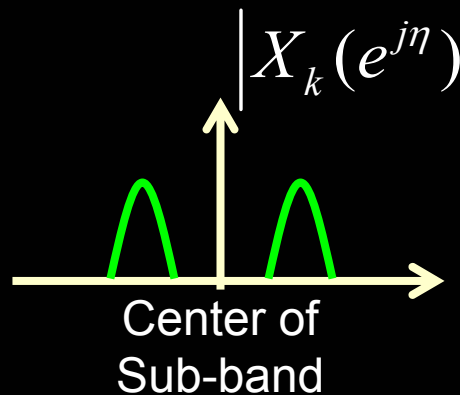 - Synchronous or coherent *carrier* detection is required to find modulations.

Symmetry Properties of Harmonic(s) in Frequency Channels

Real and Non-Negative Envelope

$$\left| X_k(e^{j\eta}) \right|$$

Center of Sub-band
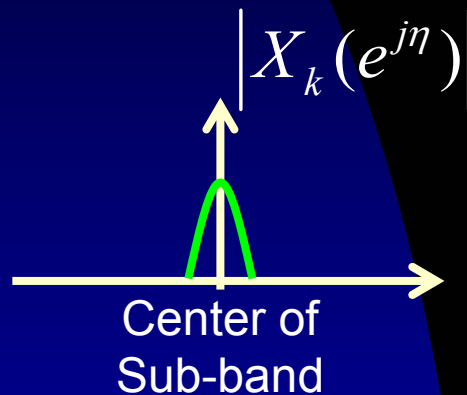
- Symmetric Positive-Definite

Real and Partially Negative Envelope

$$\left| X_k(e^{j\eta}) \right|$$

Center of Sub-band

- Symmetric Not Positive-Definite

Complex Envelope

$$\left| X_k(e^{j\eta}) \right|$$

Center of Sub-band
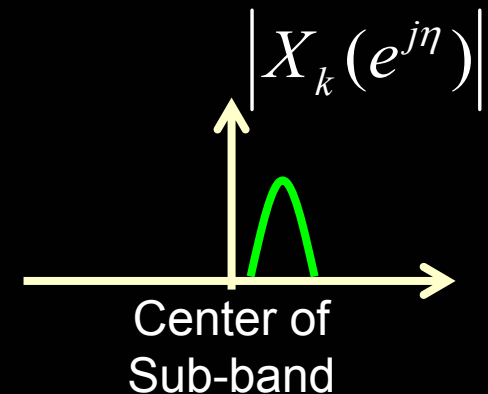
- Not-Symmetric Not Positive-Definite

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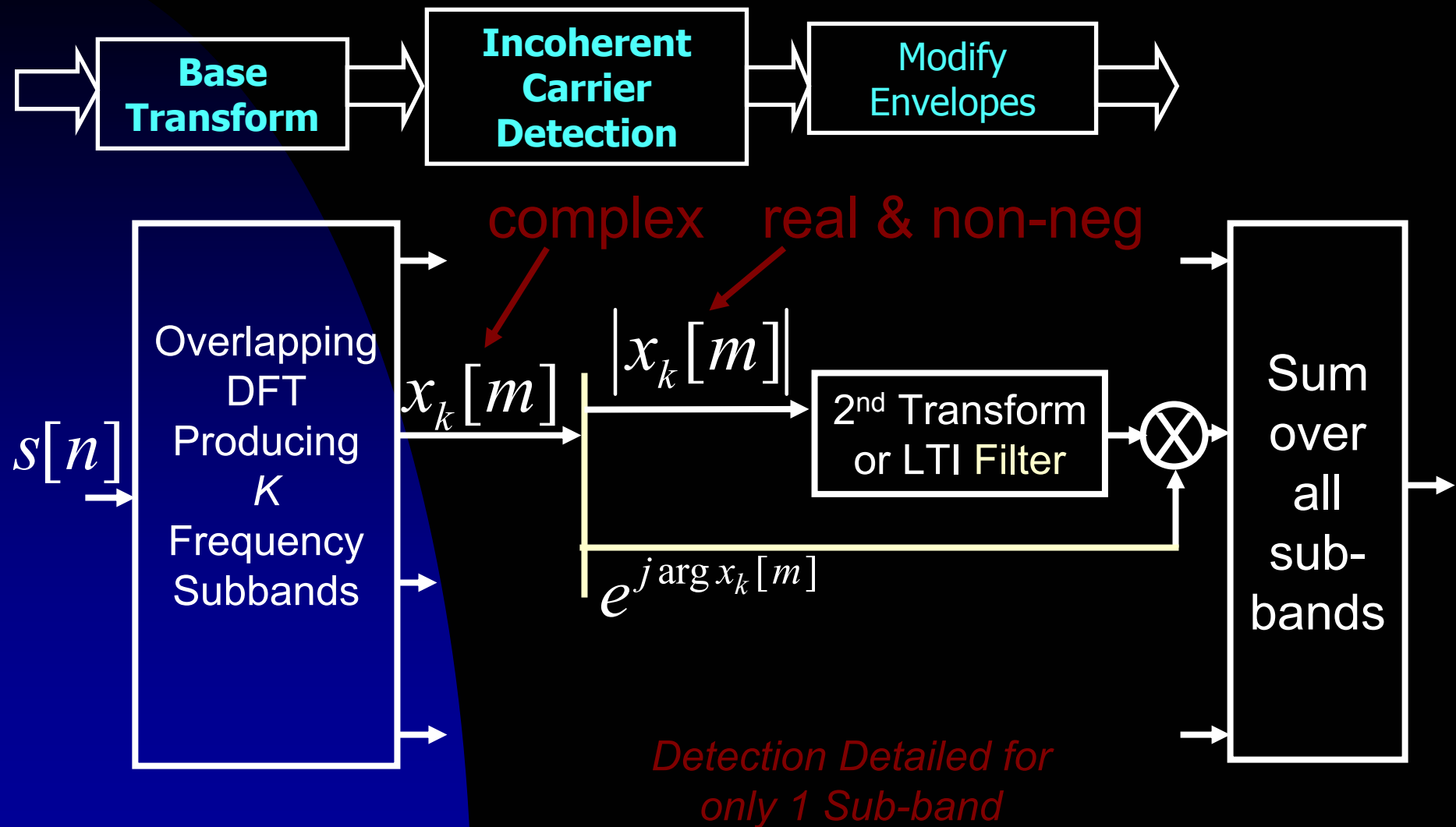
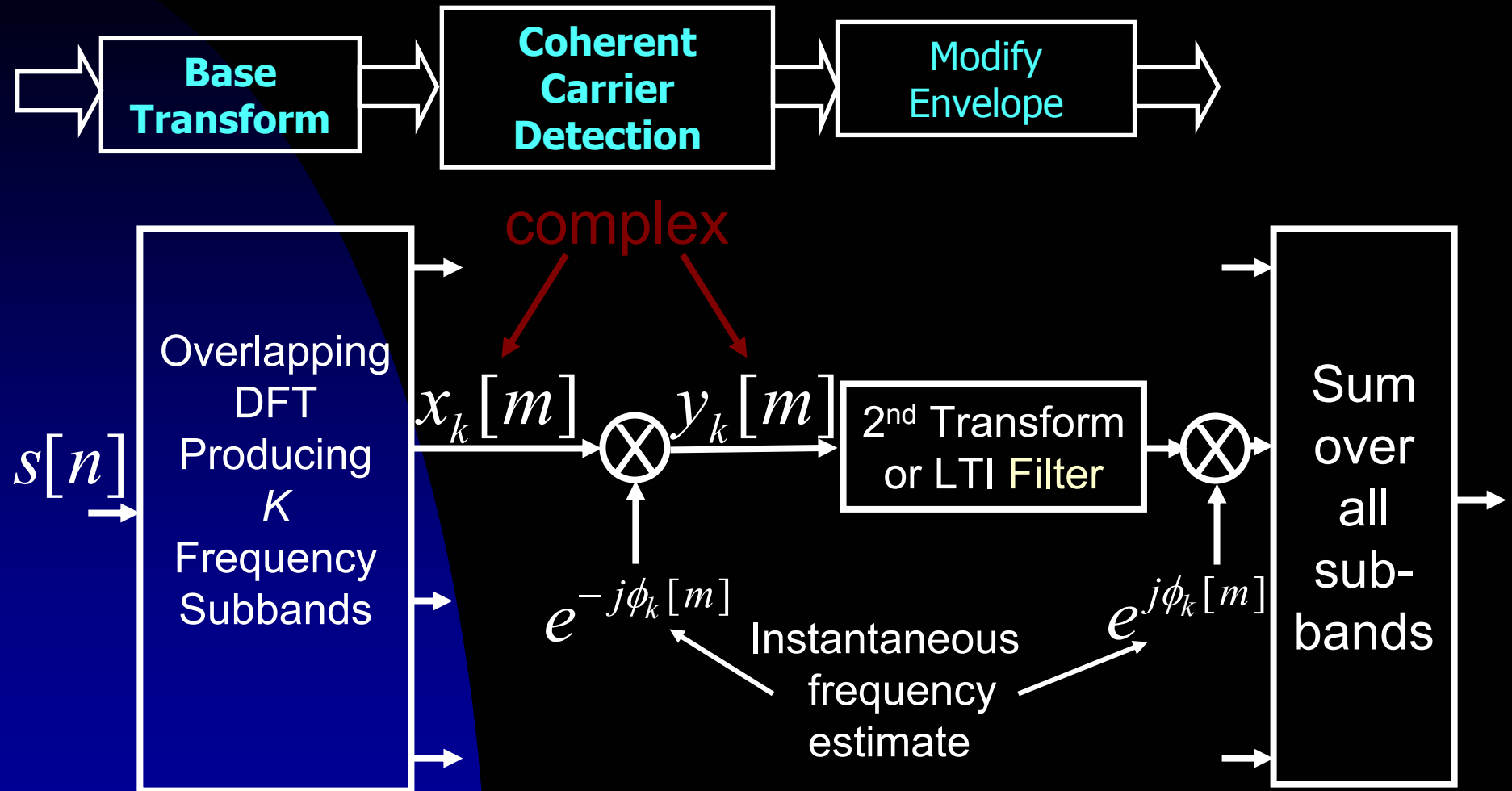# More Foundation

- Modulation filtering needs to be analogous to our usual notion of distortion-free linear time-invariant filtering
  - ◆ No distortion, i.e. should not spill energy out of a frequency sub-band.
    - ☞ Hilbert envelope has this distortion [Ghitza].
  - ◆ Frequency-shift invariance for the input signal
  - ◆ Time-shift invariance for the modulation envelope
  - ◆ Superposition!

Previously:
Incoherent Approaches

Base Transform → **Incoherent Carrier Detection** → Modify Envelopes

complex   real & non-neg

$s[n]$ → Overlapping DFT Producing *K* Frequency Subbands

$x_k[m]$

$\left|x_k[m]\right|$ → 2nd Transform or LTI Filter → ⊗

$e^{j\arg x_k[m]}$

Sum over all sub-bands

Detection Detailed for only 1 Sub-band

Proposed:
Coherent Modulation Transform

Base Transform

Coherent Carrier Detection

Modify Envelope

complex

$s[n]$

Overlapping DFT Producing K Frequency Subbands

$x_k[m]$

$y_k[m]$

2nd Transform or LTI Filter

Sum over all sub-bands

$e^{-j\phi_k[m]}$

$e^{j\phi_k[m]}$

Instantaneous frequency estimate

Detection Detailed for only 1 Sub-band

atlas@ee.washington.edu

Detection Types

$$X_k(e^{j\eta}) = \left| X_k(e^{j\eta}) \right| e^{j \angle X_k(e^{j\eta})}$$

0

$$Y_k(e^{j\eta})$$

0
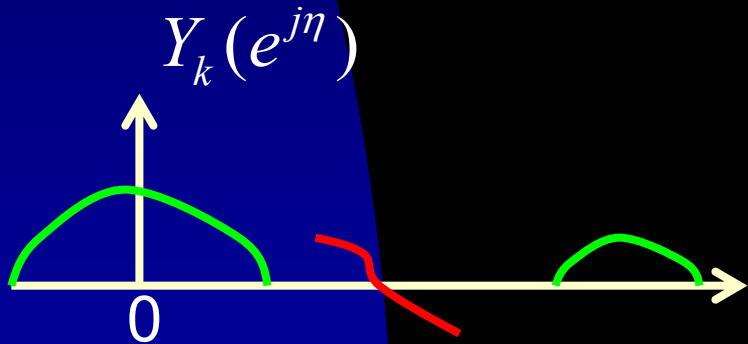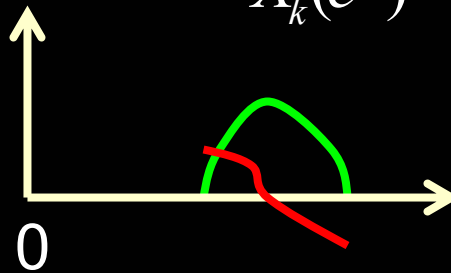
Incoherent carrier detection,
e.g. magnitude detector:

$$Y_k(e^{j\eta})$$

0
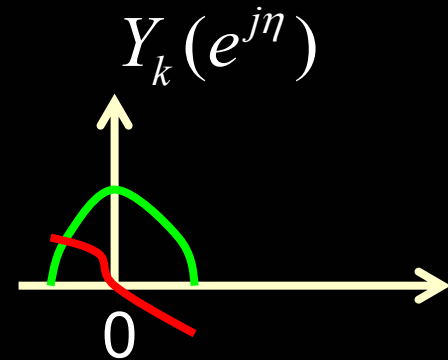
Coherent Carrier Detection

The Key Test:
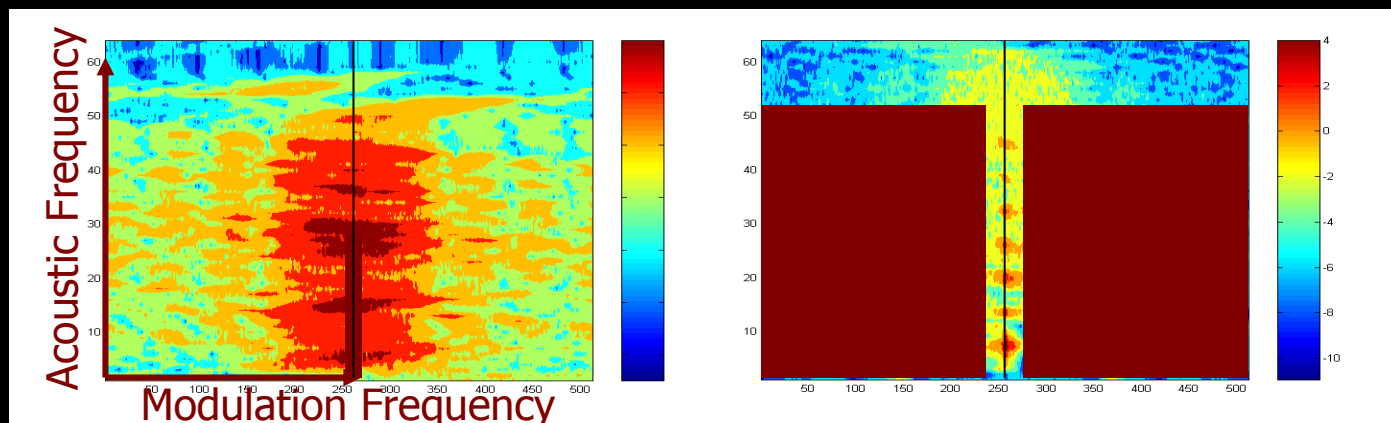# Modulation Spectra of a Modulation Filtered Signal

Input Modulation
Spectra
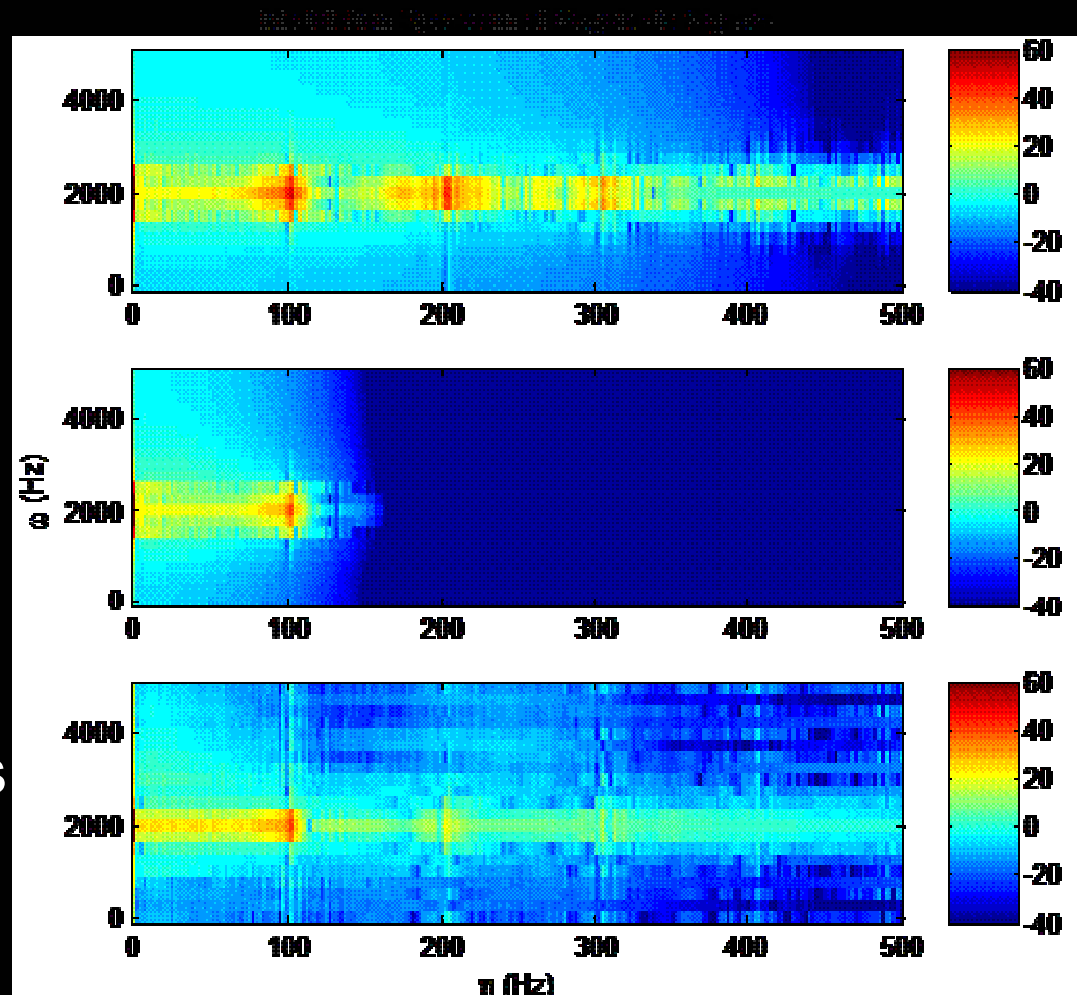
After our coherent
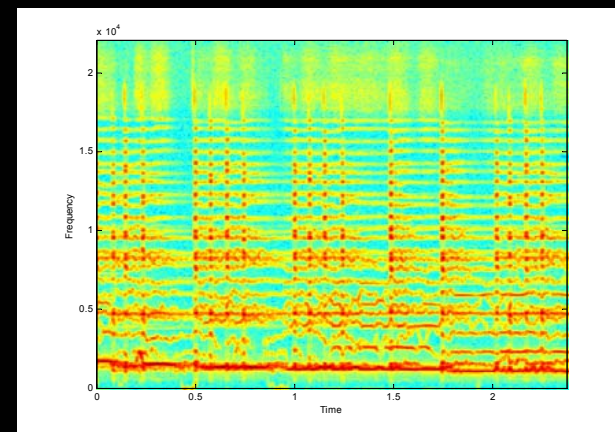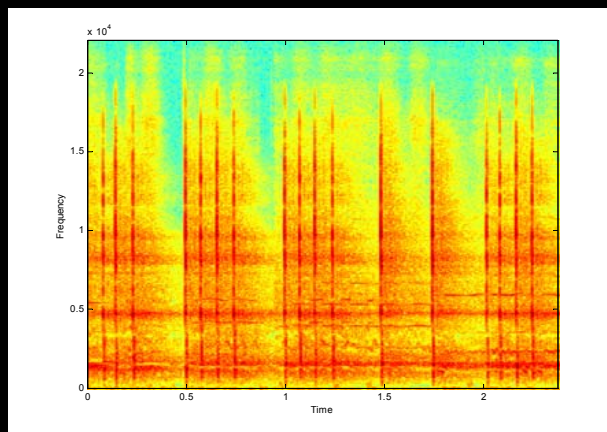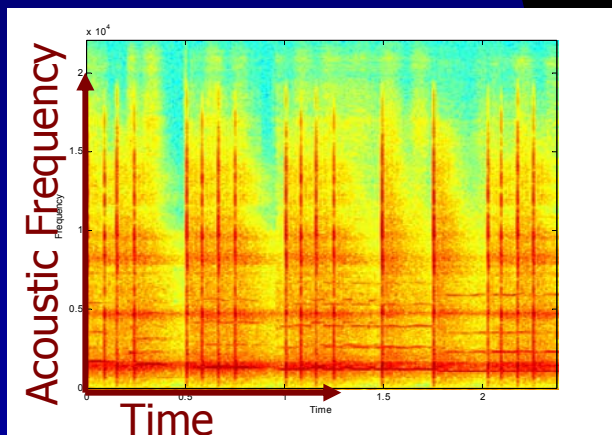modulation filtering

After asynchronous
modulation filtering

Results: Coherent Separation of Flute from Castanets

Castanets filter

Flute filter

Single Channel Input   Separated castanets **only**   Separated flute **only**

Conclusions

- Standard magnitude or Hilbert envelope modulation spectral filtering or, in general, **any other modification of a spectrogram magnitude**, will almost always cause artifacts.
    - ◆ The greater the modification, the greater the artifacts.

- Coherent modulation spectra offer an artifact-free approach to modulation filtering.
    - ◆ Potentially better separation engine for others' approaches.
    - ◆ Coherent modulation spectral displays may show new detail in speech and its environment, such as reverberation.

- Coherent approaches may offer other new insights into audition, speech, and signal modification.

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