Time-frequency-modulation representation of stochastic signals

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Introduction

- Modulated noise processes:
  - biomedical signals, e.g., with heartbeat/breathing
  - chemical plant affected by daily temperature variations
  - radiological or electromagnetic noise from machinery
  - passive sonar, turbines, road noise, voiced speech, etc.

$$x_n = w_n \left(1 + \sum_{h=1}^{H} m_h \cos \left(\frac{2\pi k_h n}{N} + \phi_h \right) \right) \qquad (1)$$

- Optimal demodulator [Van Trees, 2001]:
  - matched filter (inverse kernel)
  - envelope extraction (squaring or rectification; smoothing)

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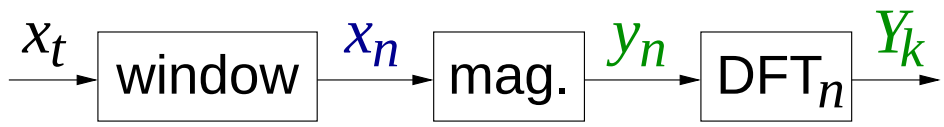
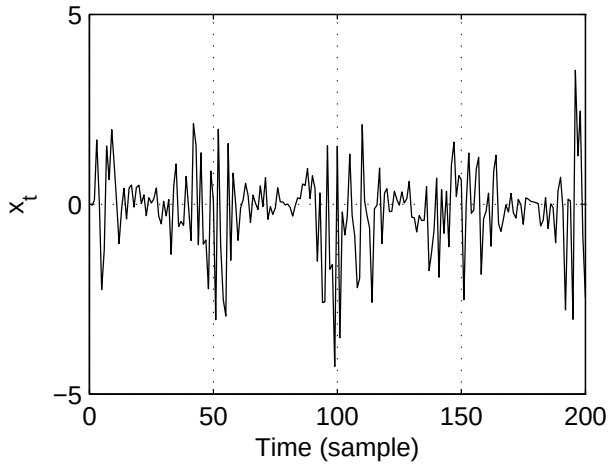
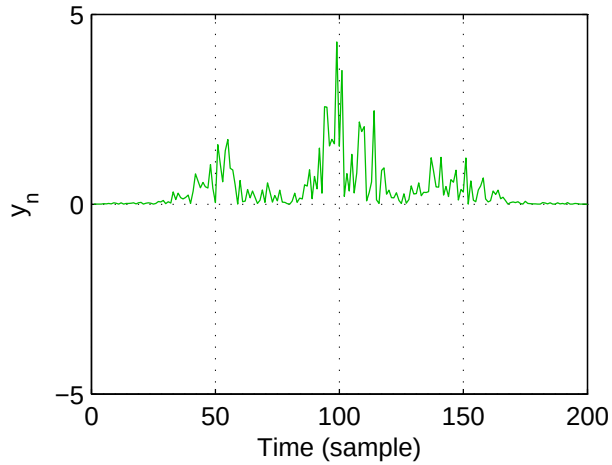
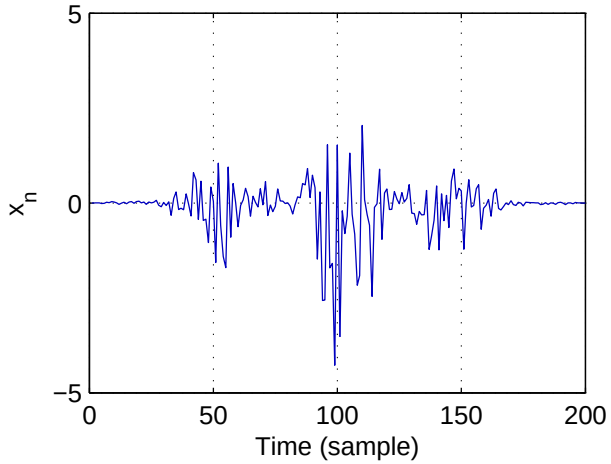
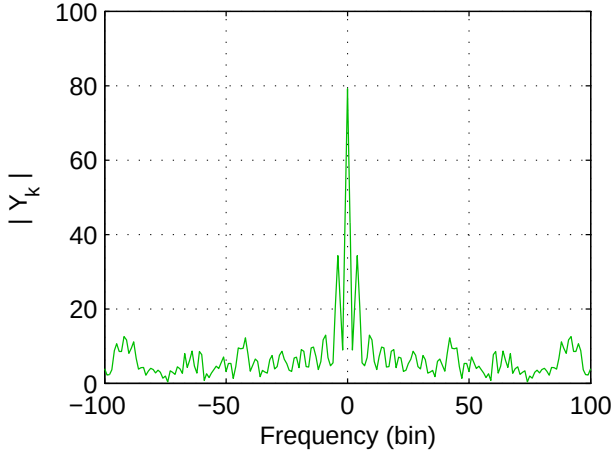
Magnitude modulation spectrum



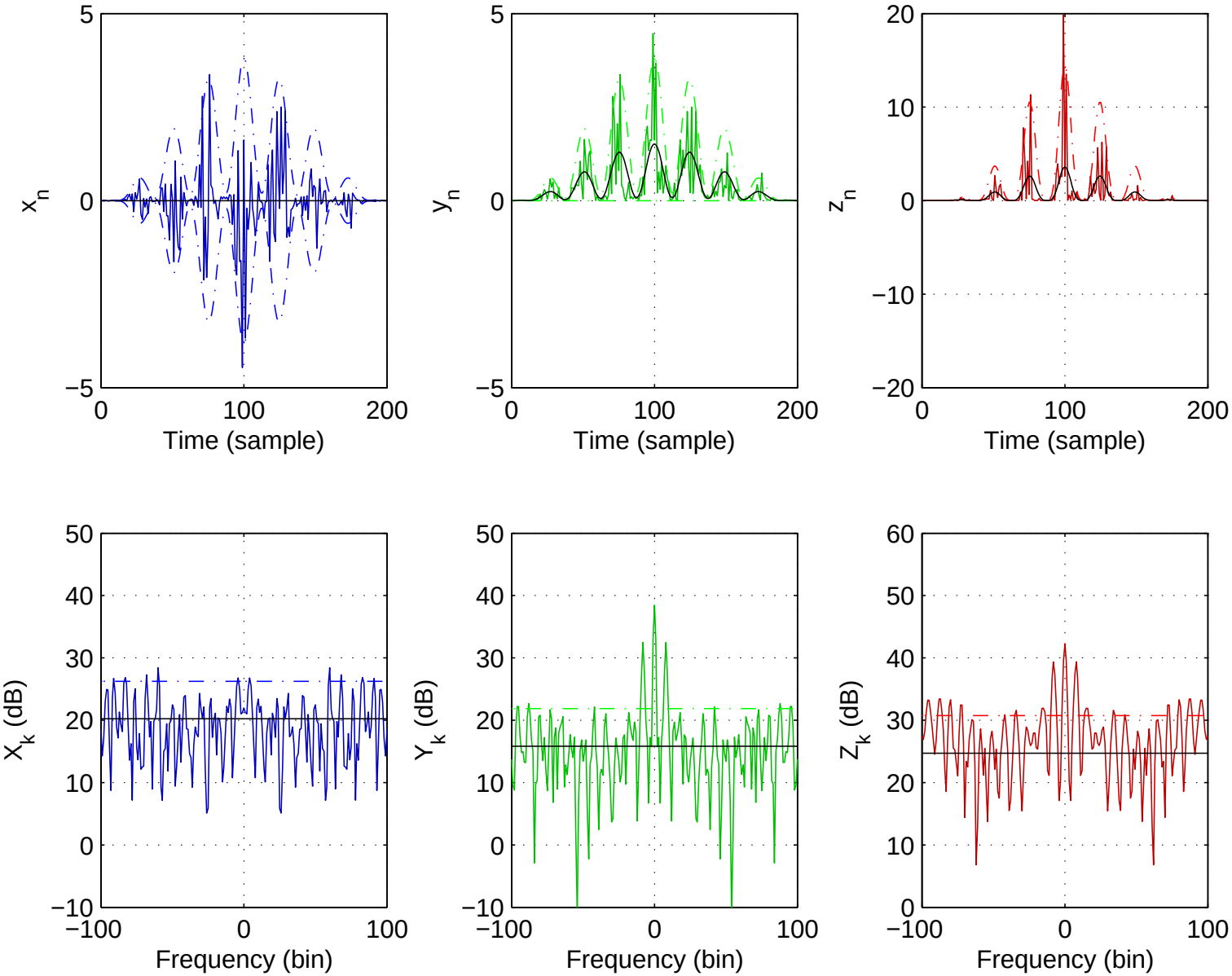




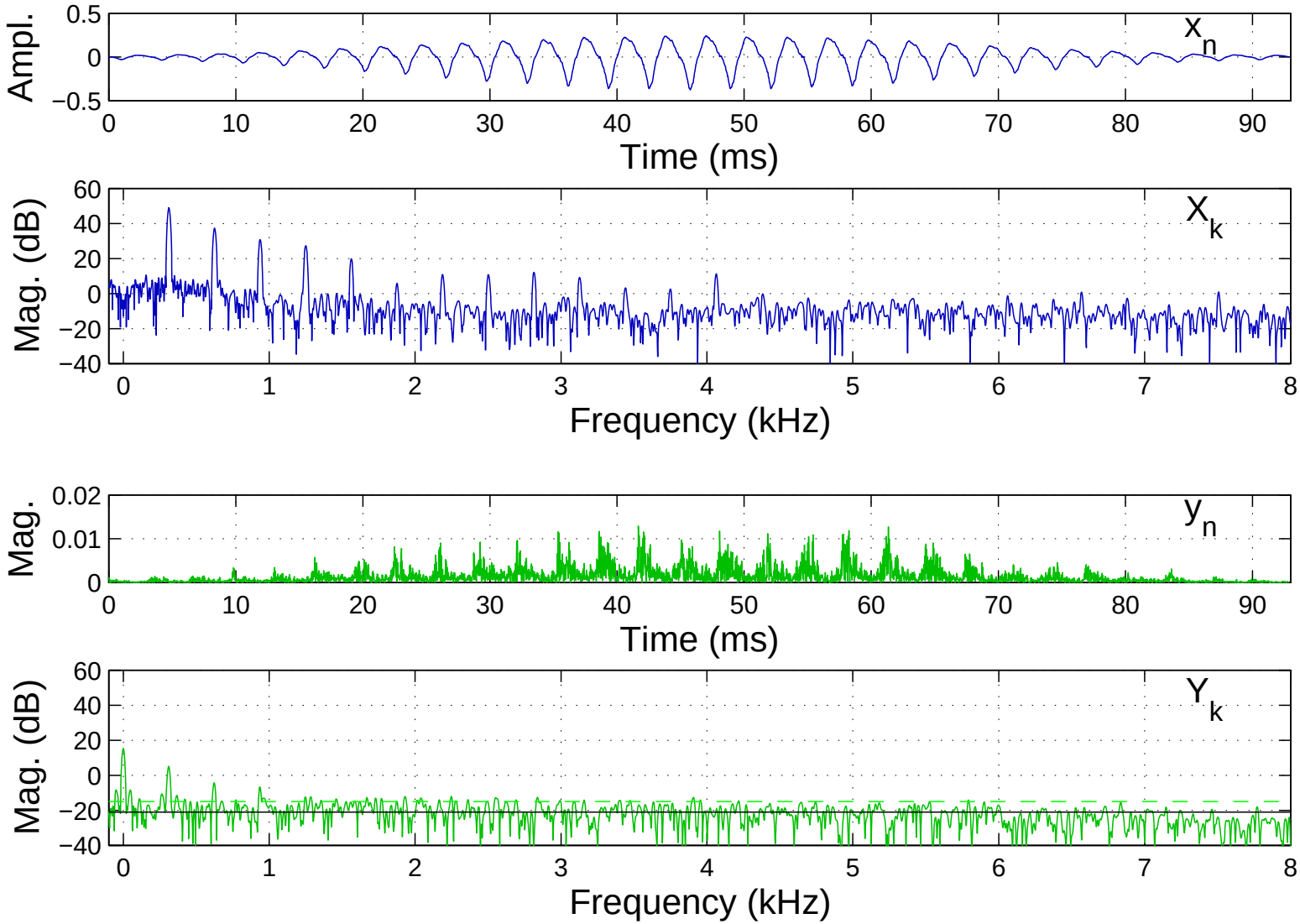




Modulated white noise (Hann)



MMS of voiced fricative speech



Modulation index estimators

First-order statistic:

$$\begin{aligned} E\{Y_k\} &= \sqrt{\frac{2}{\pi}} N\sigma \left[\delta(k) + \frac{m}{2}\delta(k \mp k_1)\mathrm{e}^{\pm j\phi_1}\right] \\ \dot{m}_1 &= 2\frac{|Y_{k_1}|}{|Y_0|} = 2\left(\frac{Y_{k_1}^* Y_{k_1}}{Y_0^* Y_0}\right)^{\frac{1}{2}} \end{aligned} \tag{2}$$

Second-order statistic:

$$\begin{aligned} E\{Y_k^* Y_k\} &= \frac{2}{\pi} N^2\sigma^2 \left[\delta(k) + \frac{m^2}{4}\delta(k \mp k_1)\mathrm{e}^{\pm j\phi_1}\right] + \theta \\ \ddot{m}_1 &= 2\left(\frac{Y_{k_1}^* Y_{k_1} - \theta^2}{Y_0^* Y_0 - \theta^2}\right)^{\frac{1}{2}} \end{aligned} \tag{3}$$

Simulation tests

- Gaussian white noise samples
  - 1200 files of 1 s duration, sampled at 44.1 kHz
- Sinusoidal modulator at $f_1 = 150$ Hz, modulation index
  - $m = 0, 0.02, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1$
- Variation of the analysis window size
  - $N = 1024, 2048, 4096, 8192, 16384$
  - 23 ms, 46 ms, 93 ms, 186 ms, 372 ms
- Variation of the modulating function
  - glide: A 0 Hz, B 20 Hz, C 60 Hz
  - jitter: A 0 %, B 0.5 %, C 1.5 %
  - multiple modulating frequencies, f_1 and f_2

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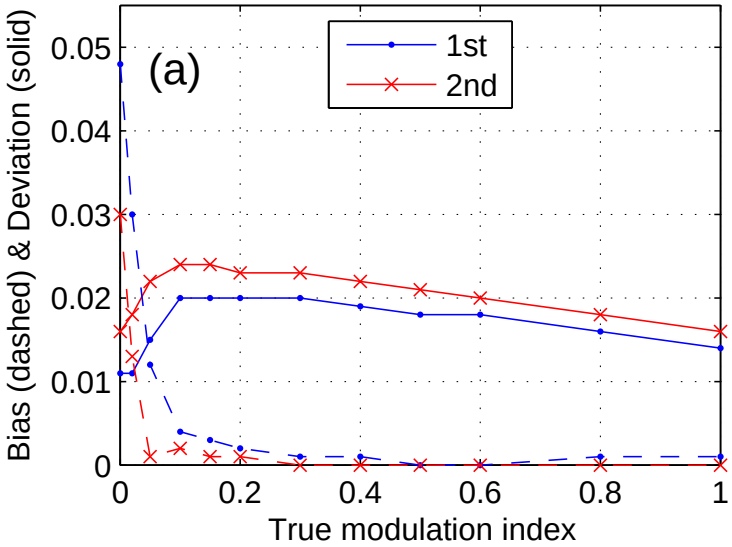
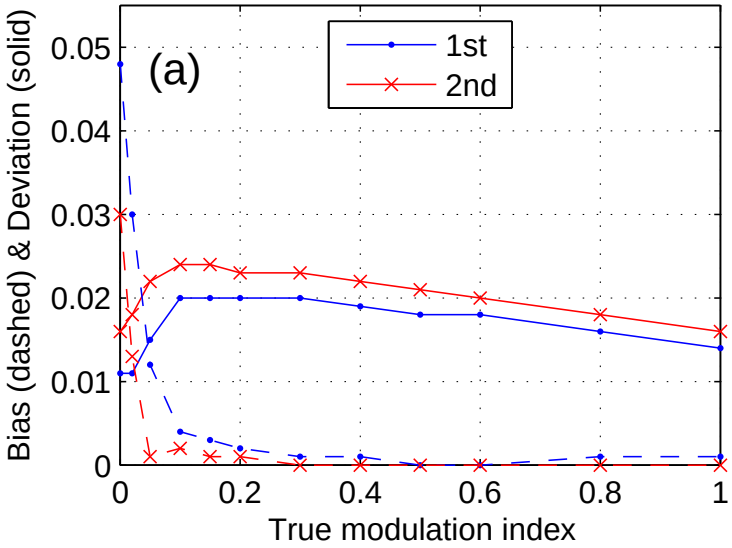
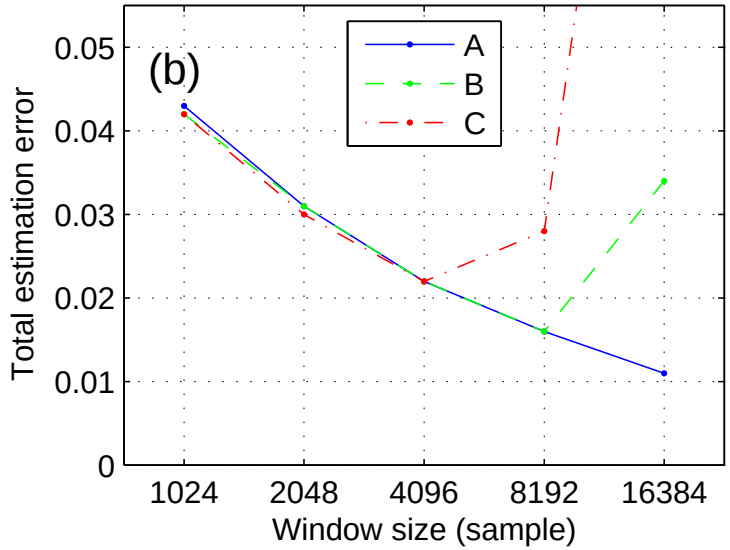
Effect of modulation index

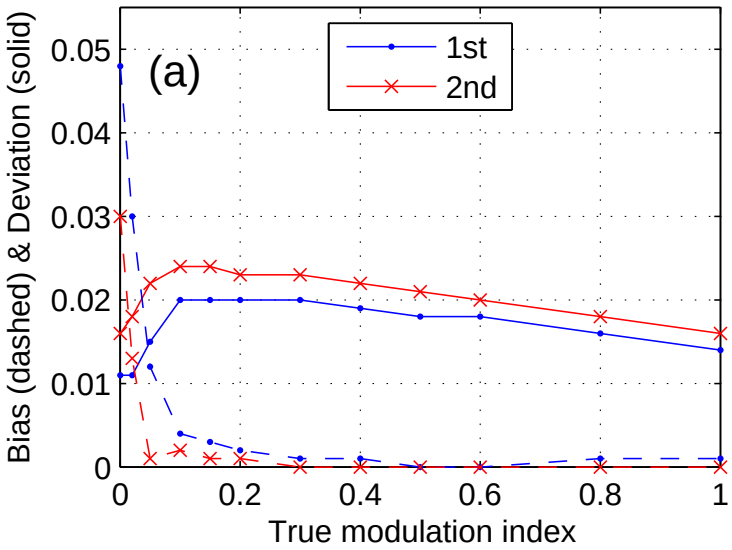


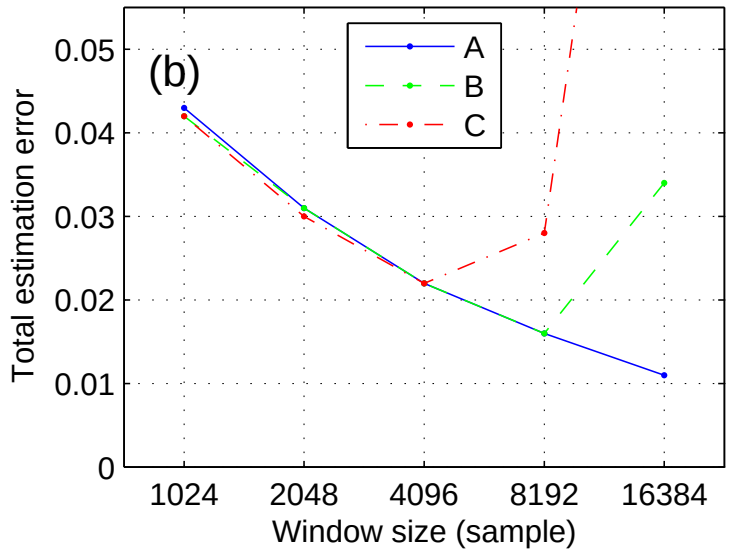
Effect of window size

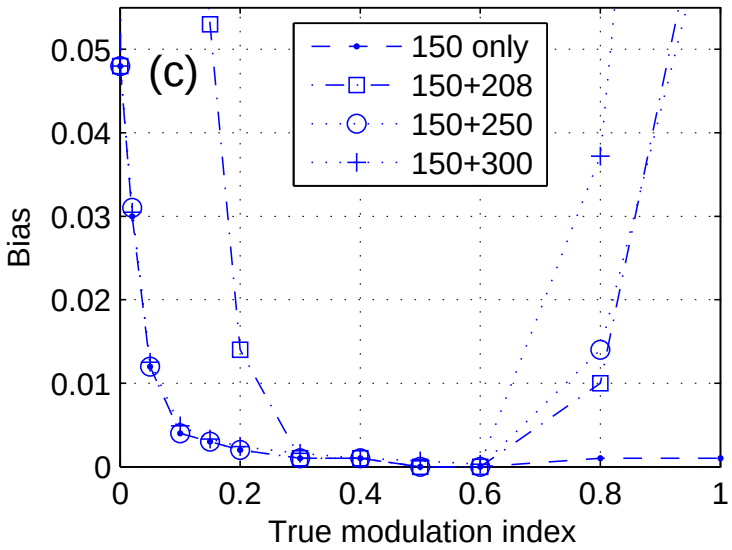


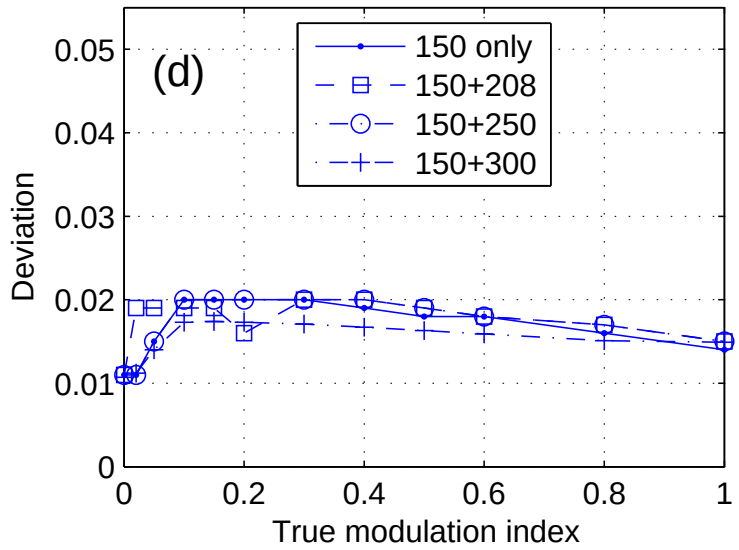


Effect of two modulators

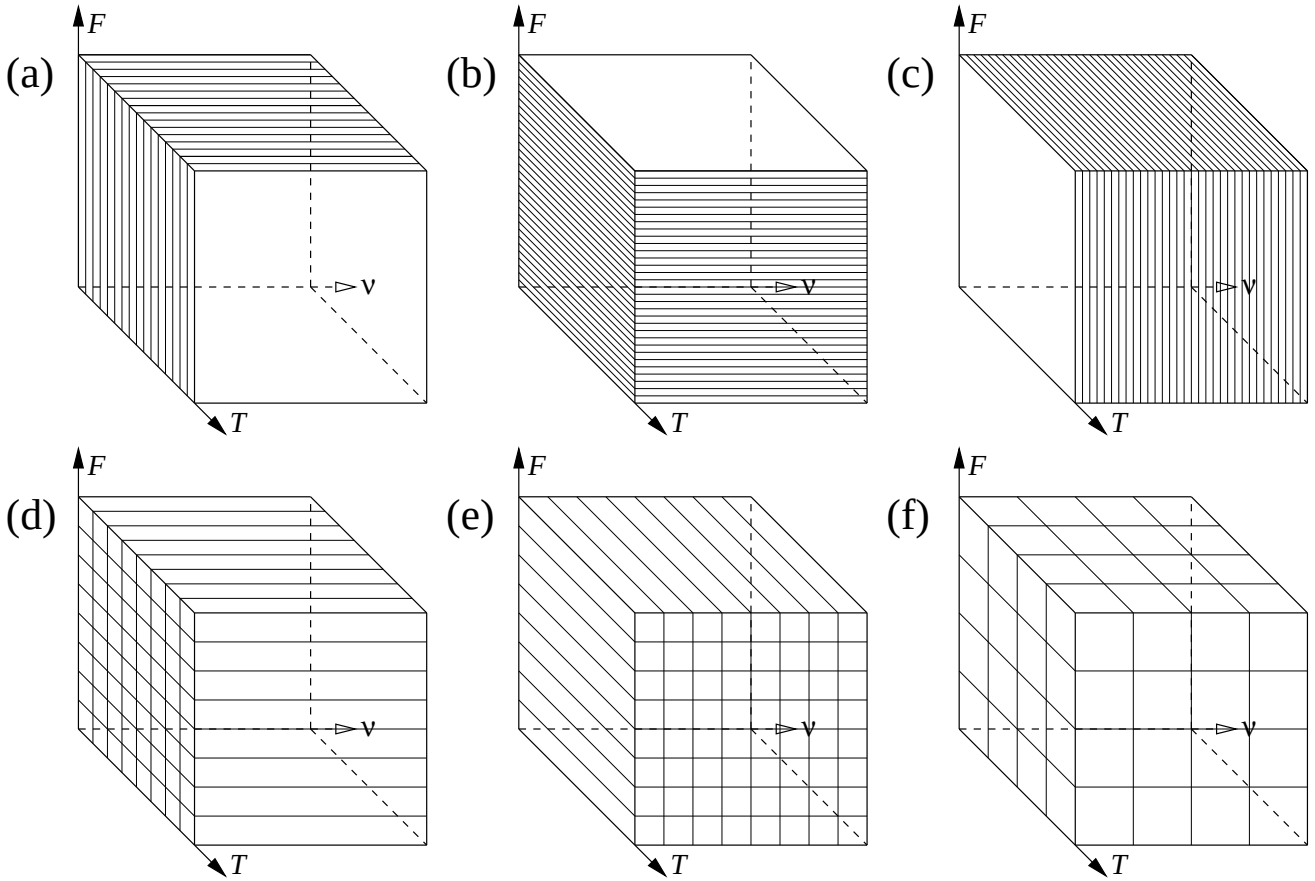




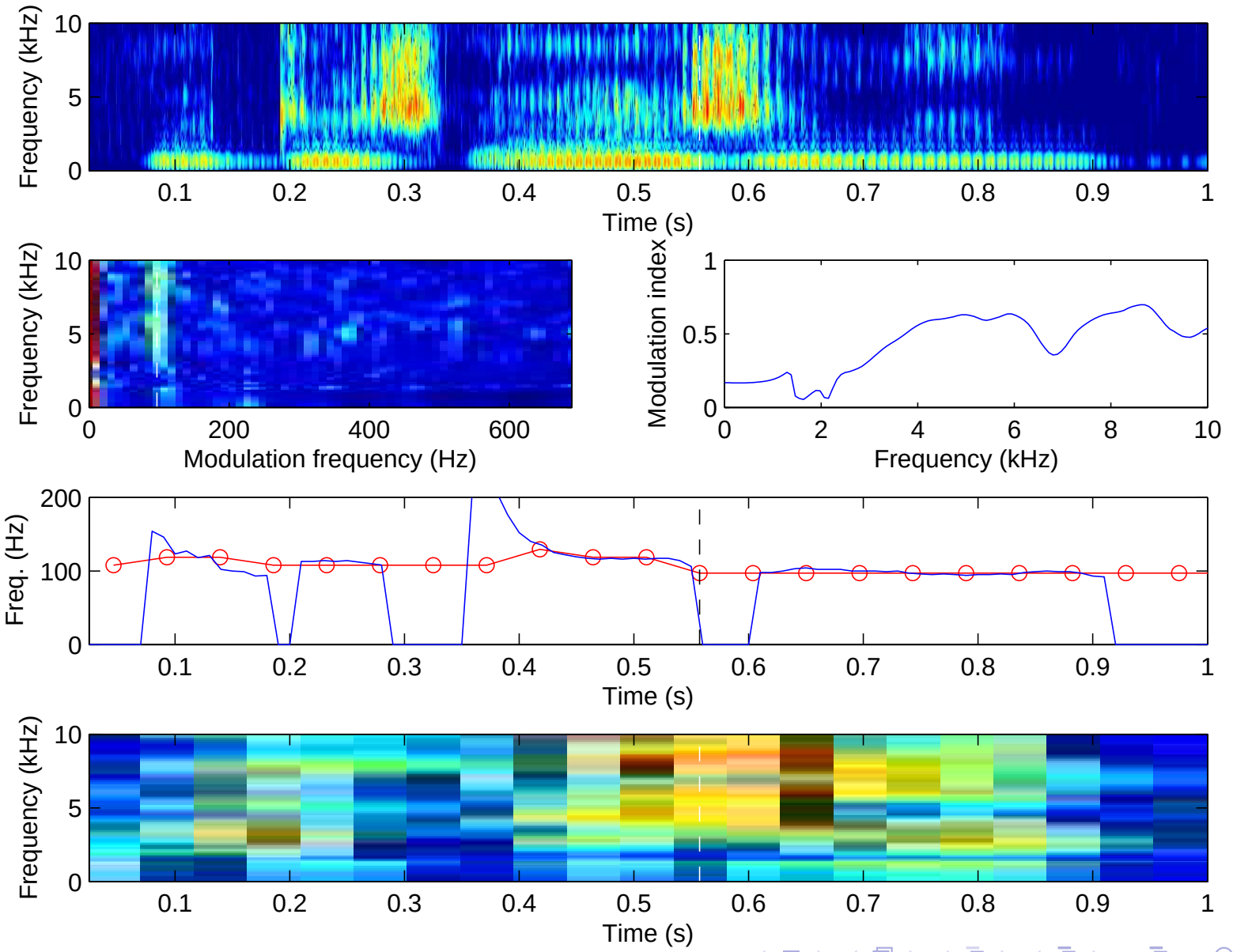




Time, frequency and modulation



TFM of voiced fricative speech



Summary

- Conclusions
  - Magnitude modulation spectrum for m of AM noise
  - Estimators developed for real time-varying signals
  - Evaluation on synthetic test signals gave low error
  - Validated separate estimation of m for f_1 and f_2
  - Time-frequency-modulation proposed
- Future investigation
  - Theoretical bounds of first-order estimator
  - Applications to real stochastic signals

More?

http://www.ee.surrey.ac.uk/personal/p.jackson/dsp07

Thanks

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