Reducing Observation Time for Reliable Cyclostationarity Feature Extraction

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Outline

Problem Statement and Motivation

Background Material

- Cyclostationarity definitions
- Robust statistics definitions
- Feature extraction method

Simulation Results

- Second-order first-conjugate observation time requirements
- Sixth-order first-conjugate observation time requirements

Conclusion

Problem Statement and Motivation

- Cyclostationarity
  - interesting feature for detection and classification
  - many digital signals are inherently cyclostationary

    [Gardner-Napolitana-Paura 2006]
  - feature extraction with minimal pre-processing

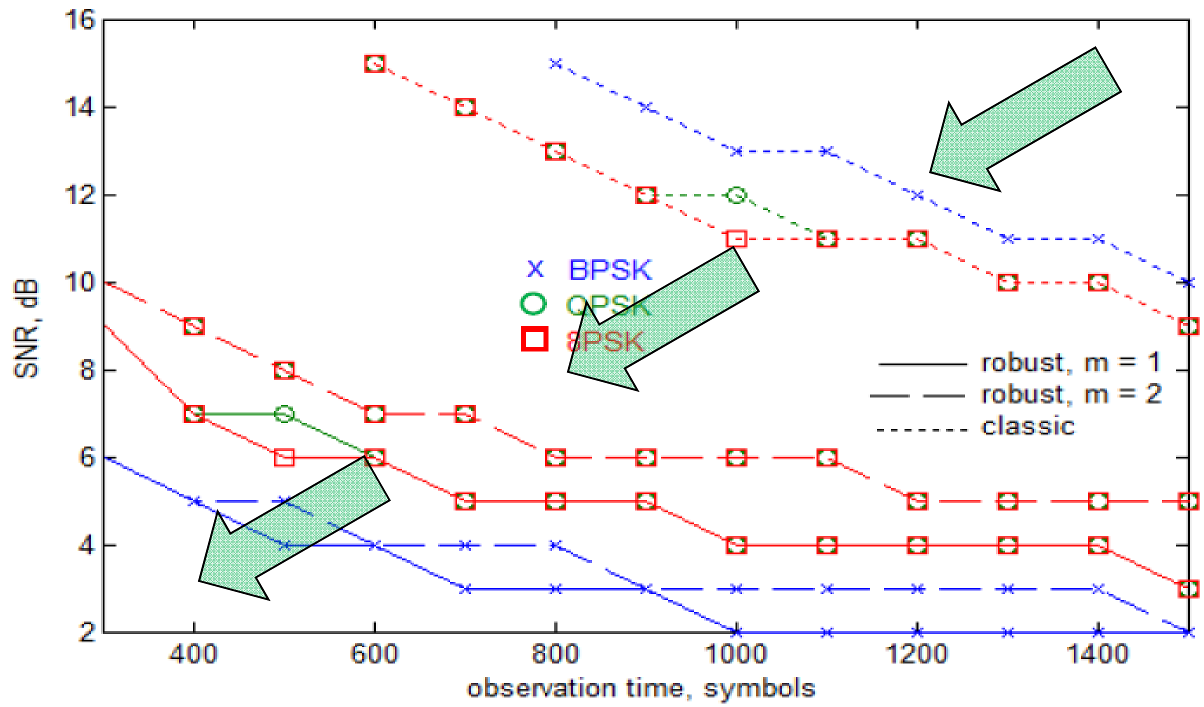
    [Dobre-Abdi-Bar-Ness-Su 2006]
- Promising reduction in SNR requirements shown when using robust statistics [Malady-Beex 2010]
- Drawback: long observation time

↑

to be addressed here

Research Goal

Reduce observation time requirements
for estimating cyclostationarity features
through incorporation of robust statistics



Background Material

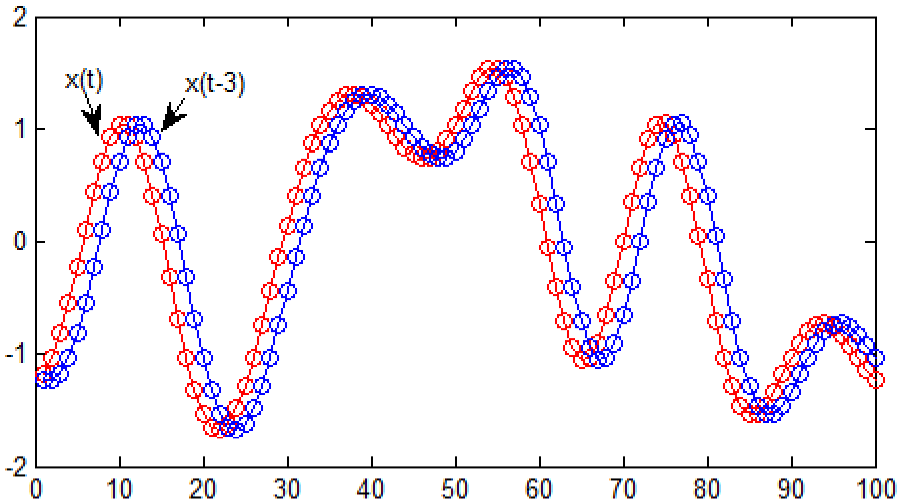
Cyclostationarity Definitions

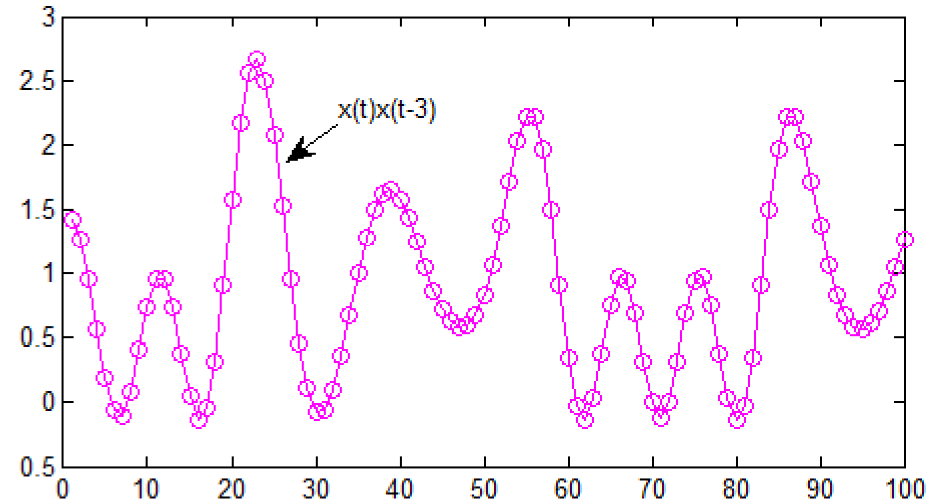
Cycle frequency when CTMF nonzero

CTMF: $$R_x^{\alpha}(\boldsymbol{\tau})_{n,q} = \lim_{Z\to\infty}\frac{1}{2Z+1}\sum_{t=-Z}^{Z} L_x(t,\boldsymbol{\tau})_{n,q}\, e^{j2\pi\alpha t}$$

[Gardner 1993]

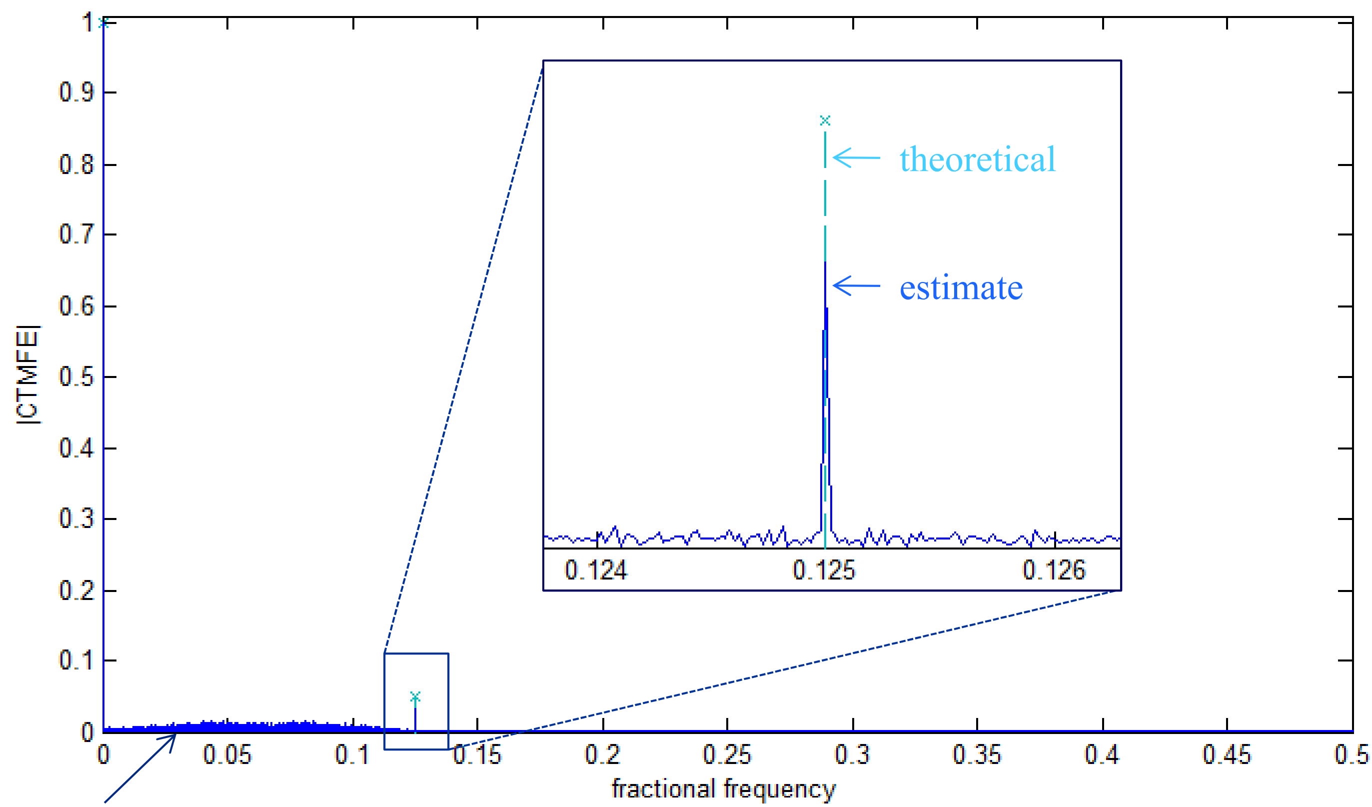
$$L_x(t,\boldsymbol{\tau})_{n,q} = \left(\prod_{j=1}^{n} x^{(q*)}(t+\tau_j)\right);\boldsymbol{\tau} = \begin{bmatrix}\tau_1 & \cdots & \tau_n\end{bmatrix}$$





Cyclostationarity Estimate

CTMFE: $$\hat{R}_x^{\alpha}(\boldsymbol{\tau})_{n,q} = \frac{1}{T}\sum_{t=0}^{T} L_{x_n}(t,\boldsymbol{\tau})_{n,q}\, e^{j2\pi\alpha t}$$



estimation variation caused by a finite observation set

CTMFE nonzero at non-cycle frequencies

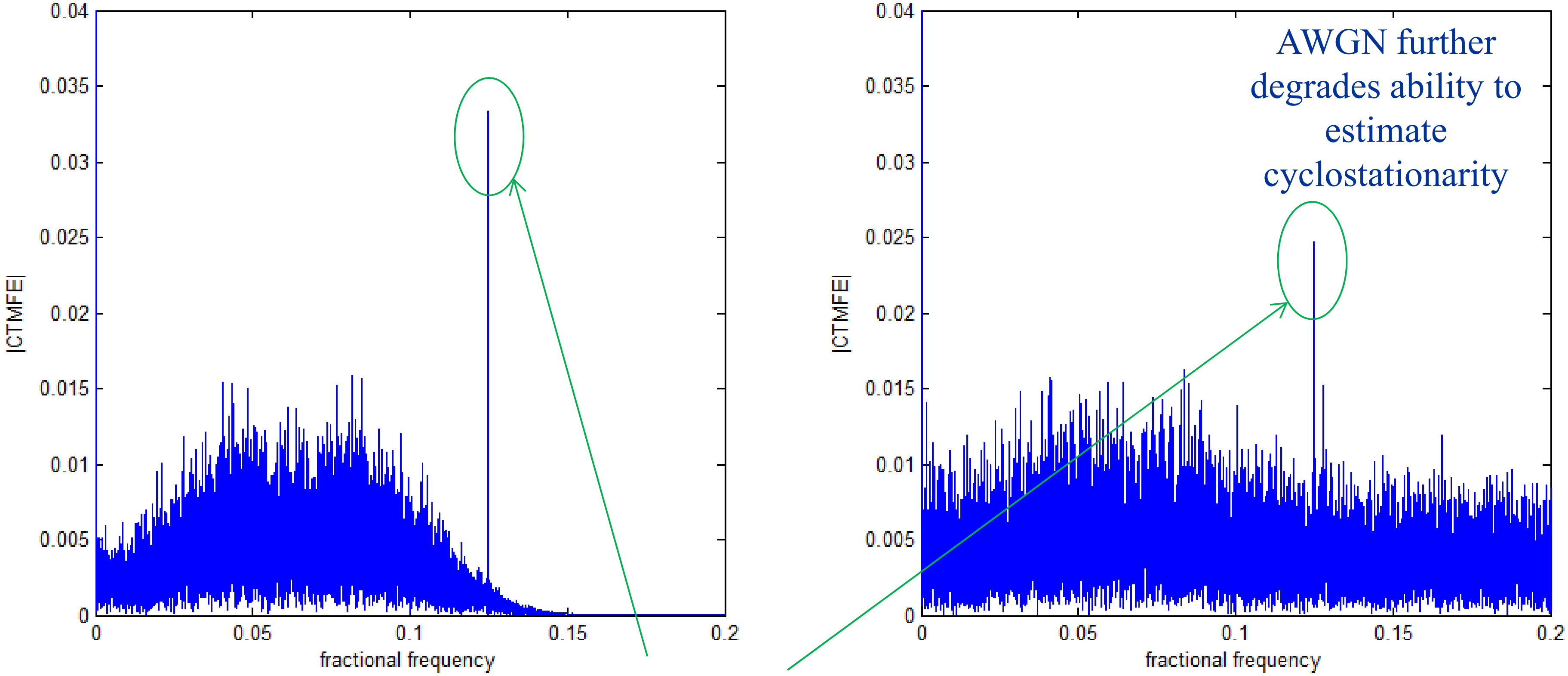
BPSK

*CF = 6000/48000 = 0.125

Cyclostationarity Estimate in the presence of noise

BPSK

NO AWGN | SNR = 5 dB

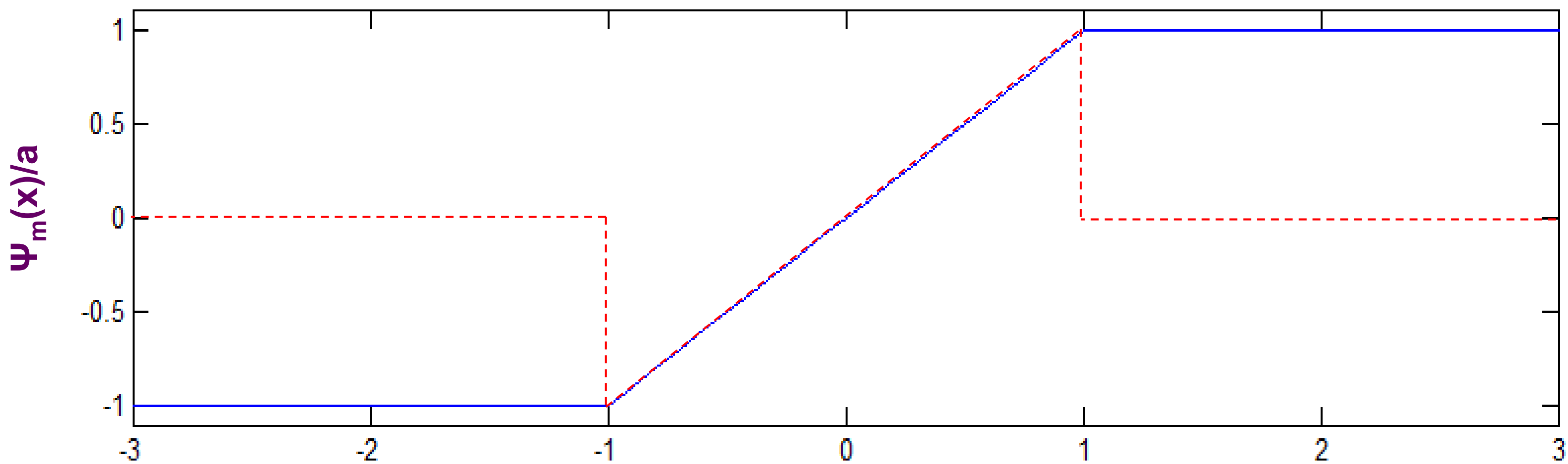


Cycle frequency

Robust Statistic Definitions

$$\tilde{R}_x^{\alpha}(0)_{n,q} = \frac{CMAD^n}{Tc} \sum_{t=0}^{T} L_{\Psi_m(x)}(t,0)_{n,q} e^{j2\pi\alpha t}$$

$$L_{\Psi_m(x)}(t,\tau)_{n,q} = \left(\prod_{j=1}^{n} \Psi_m^{(*)} \left(\frac{x(t+\tau_j)}{CMAD} \right) \right); \tau = [\tau_1 \quad \cdots \quad \tau_n]$$



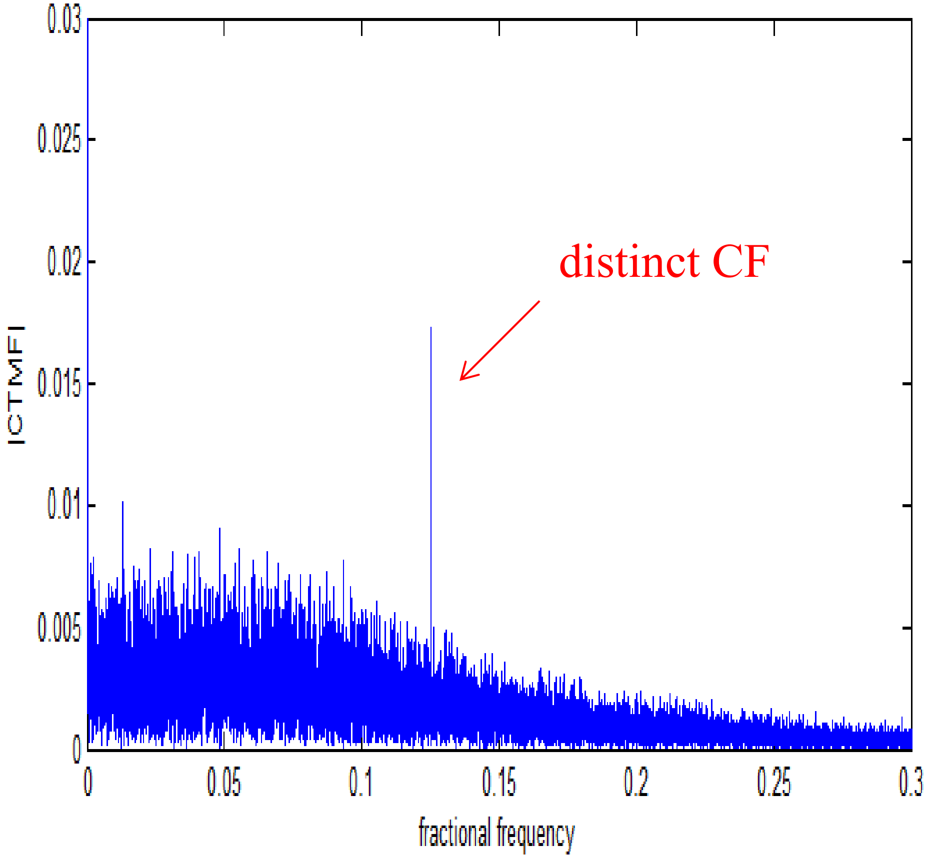
$$\Psi_{m=1}(x) = \begin{cases} x & for\,|x| \le a \\ a\dfrac{x}{|x|} & for\,|x| > a \end{cases}$$

$$\Psi_{m=2}(x) = \begin{cases} x & for\,|x| \le a \\ 0 & for\,|x| > a \end{cases}$$

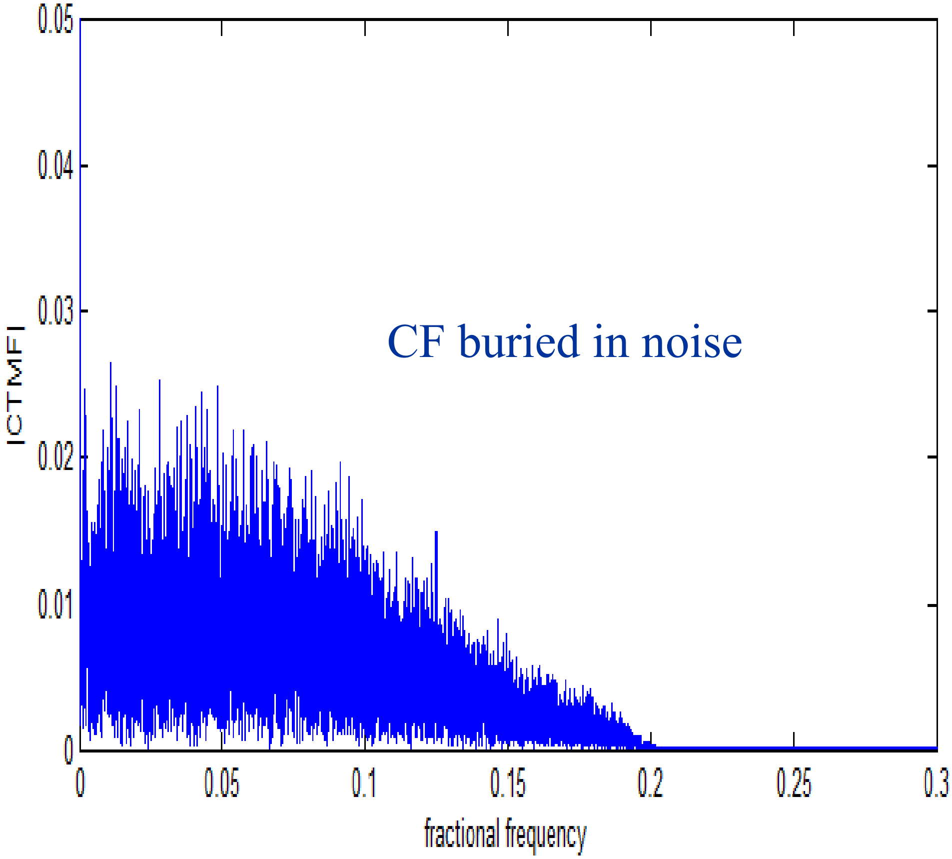
$$\hat{\theta}_{CMAD} \triangleq \gamma\, median\,|\mathbf{x}|$$

Improvements from using the Robust CTMFE

Robust $\Psi_{m=1}(x)$



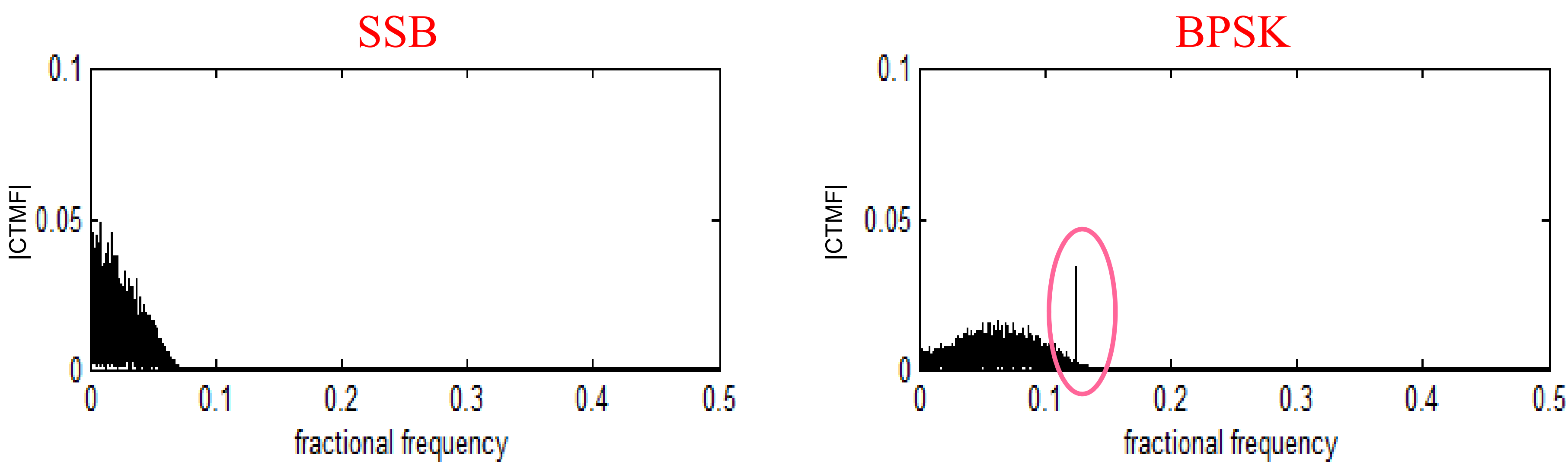
Classic



BPSK @ SNR = 0 dB

Statistical Test for Presence of Cycle Frequencies

1. Search for a peak

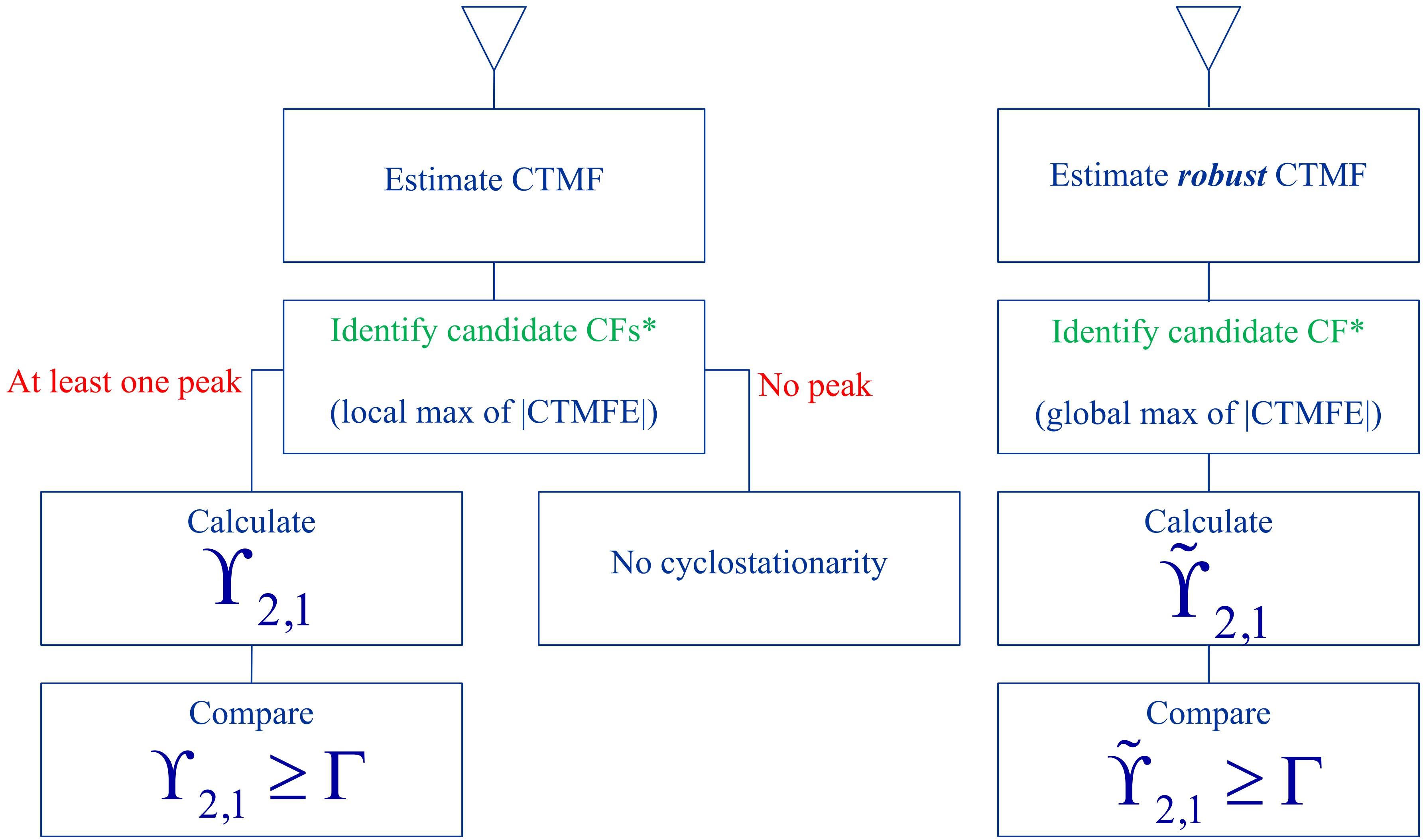


2. Calculate $\Upsilon_{n,q}$

[Dandawade-Giannakis 1994]

3. $\Upsilon_{n,q} \overset{?}{\geq} \Gamma$

Robust test vs. Classic Test

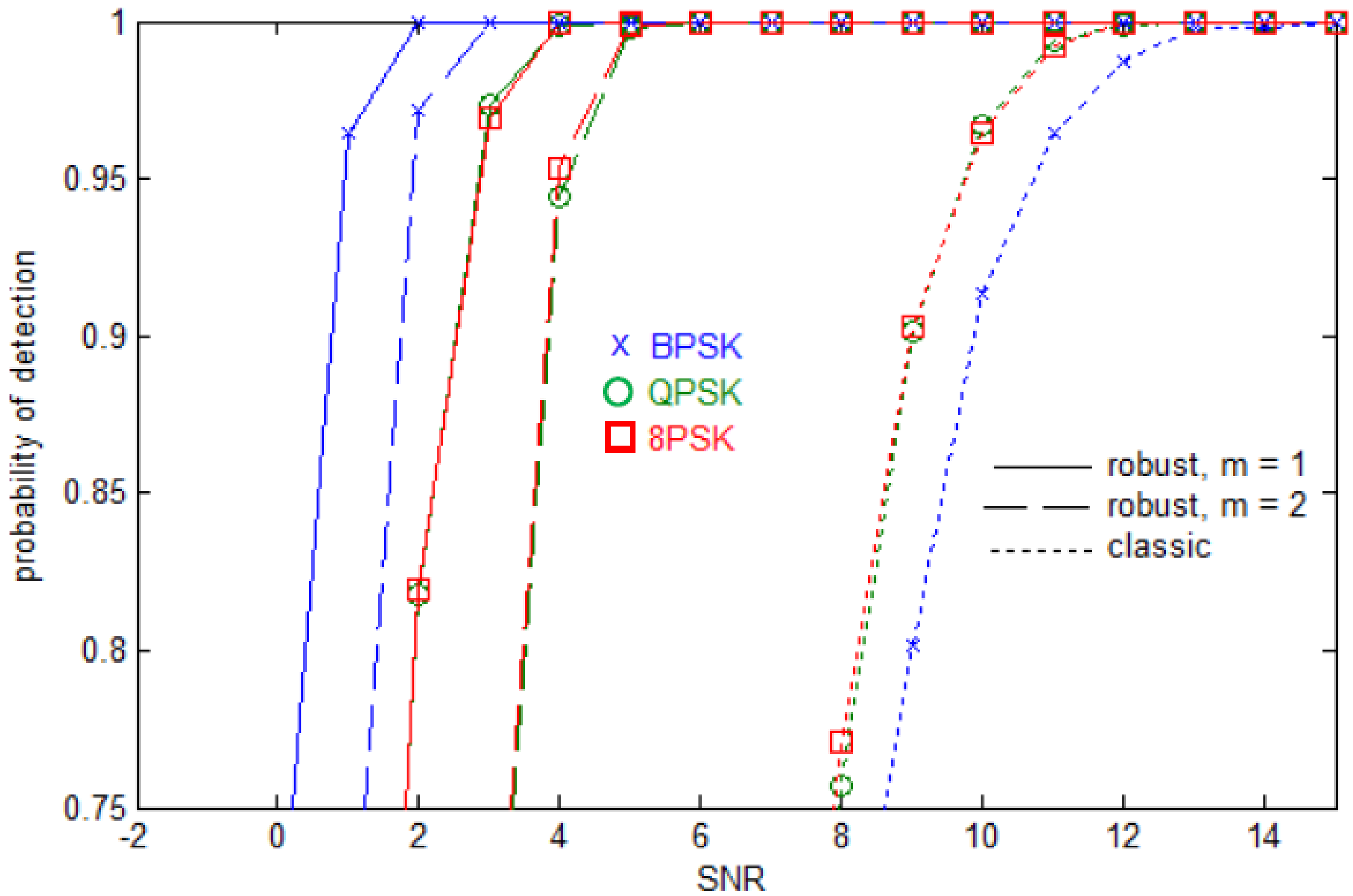


*Two methods to identify candidate CFs: local max and global max.
Local max criteria: |CTMFE| at least ~4 times larger than "nearest neighbors."
(10000 bins in FFT, used nearest ~400 neighbors)

Observation Time Requirements

Simulation Results: Second-Order First-Conjugate Cyclostationarity Detection

Observation time = 1500 symbols
Sample rate = 100 kHz
Symbol rate = 10 kHz



Simulation Results: Second-Order First-Conjugate Cyclostationarity Detection

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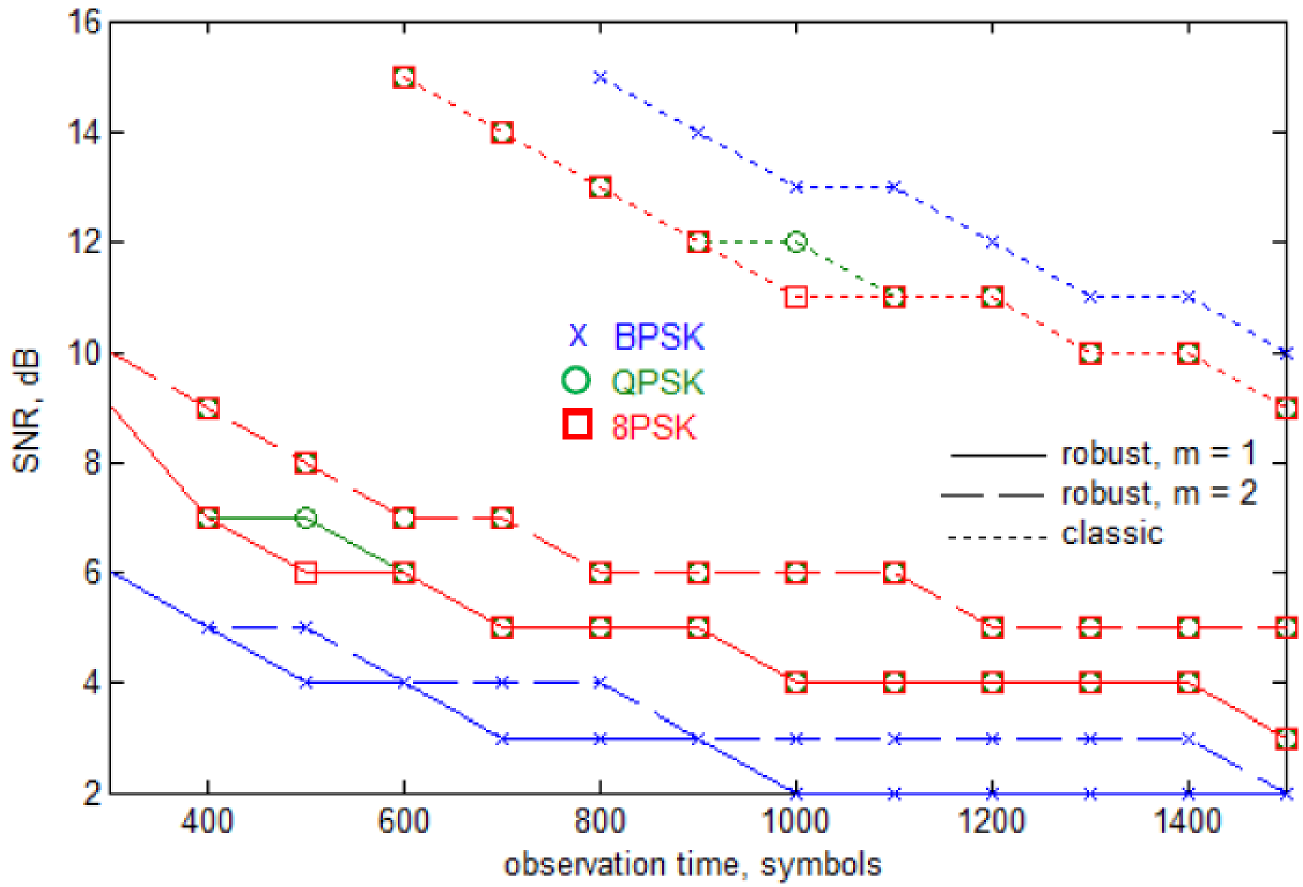
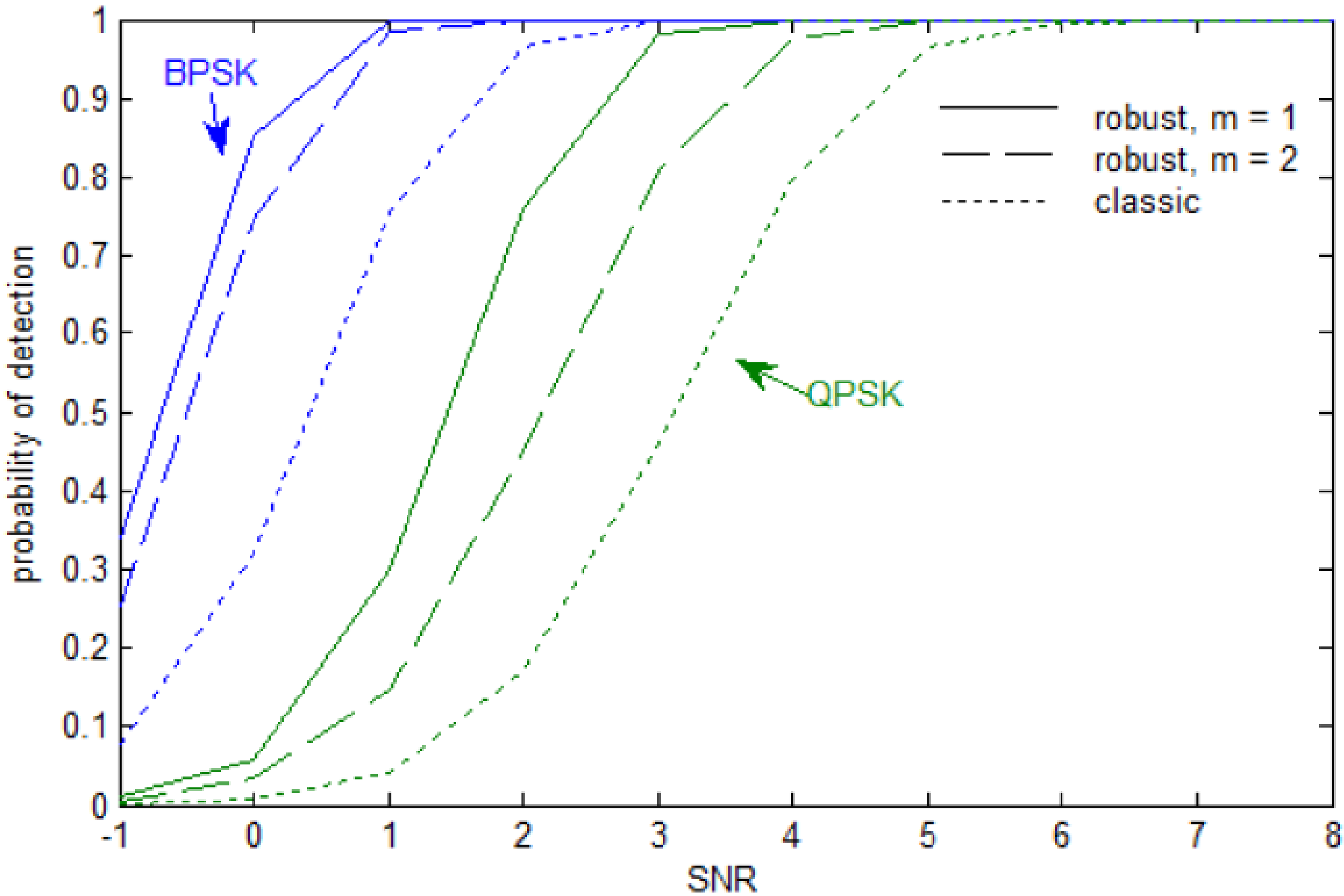


The robust (solid) curves represent (99;1)% reliability;
the classic (dashed) curves represent (90;1)% reliability.

Simulation Results: Sixth-Order First-Conjugate Cyclostationarity Detection

Observation time = 1500 symbols
Sample rate = 100 kHz
Symbol rate = 10 kHz

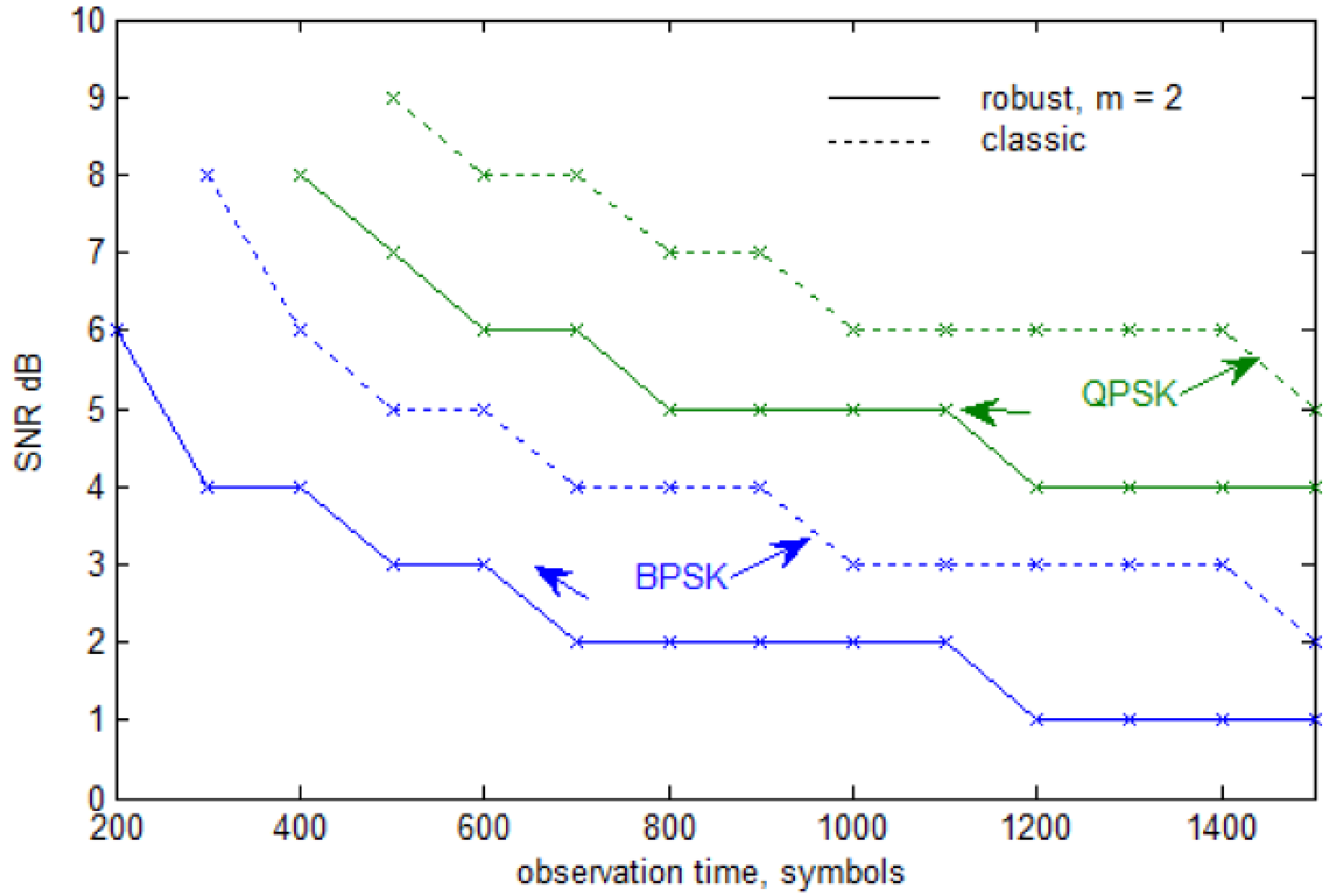


Note: 8PSK does not exhibit 6,1* cyclostationarity

Simulation Results: Sixth-Order First-Conjugate Cyclostationarity Detection

Sample rate = 100 kHz
Symbol rate = 10 kHz

BPSK: m = 1 and m = 2 identical
QPSK, m=1 (not shown) has 1 dB improvement



Note: 8PSK does not exhibit 6,1* cyclostationarity

For classic and robust (99;1)% reliable detection of sixth-order first-conjugate cyclostationarity.

Conclusions

- Use of robust statistics reduced observation time and/or improved reliability for second-order first-conjugate CS feature detection

- Sixth-order first-conjugate CS feature detection also quicker and/or more reliable when using robust statistics

- Compared performance of two different influence functions
  - Performance vs complexity trade-off

- Applications in detection and classification problems
  - Dynamic spectrum access
  - Monitoring

Questions?

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