COMPARISON AND SIMULATION OF DIGITAL MODULATION RECOGNITION ALGORITHMS

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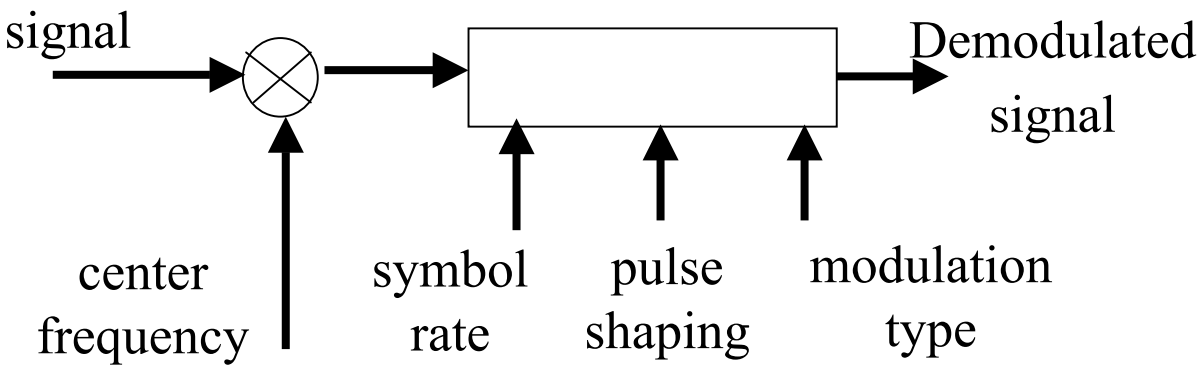
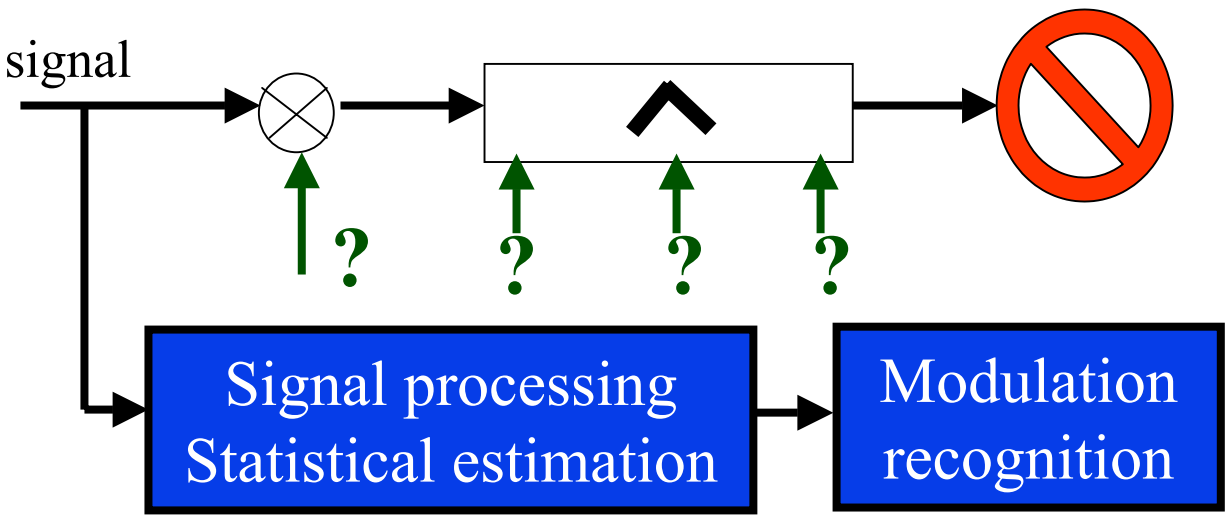
CECOM Bottom Line: THE WARFIGHTER

Automated Signal Exploitation and Modulation Recognition

Cooperative Communication



Non-cooperative Communication



Factors Affect the Modulation Recognition Results

- Residual carrier frequency estimation
- Carrier frequency and phase tracking
- Baud rate estimation and pulse timing
- Pulse shaping recovery
- Channel distortion

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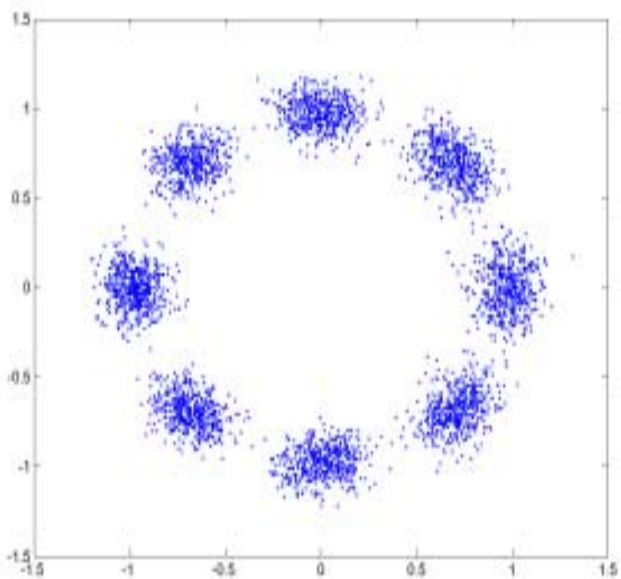
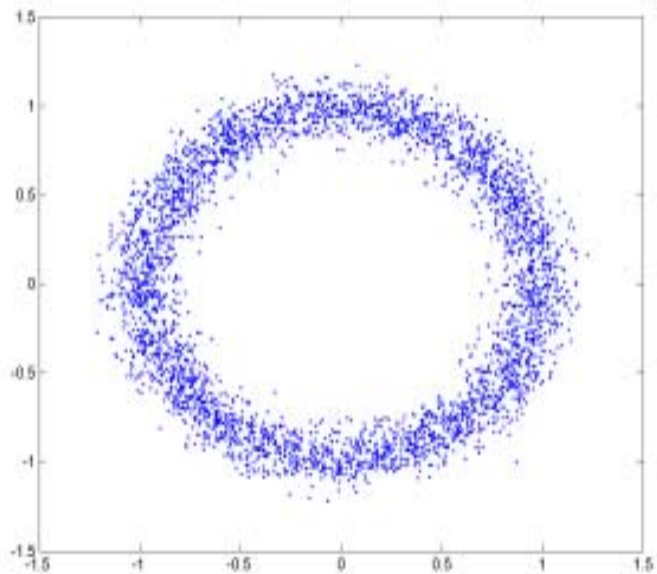
Center frequency offset



A PSK8 signal



PSK8 signal with phase shift produced by center frequency offset

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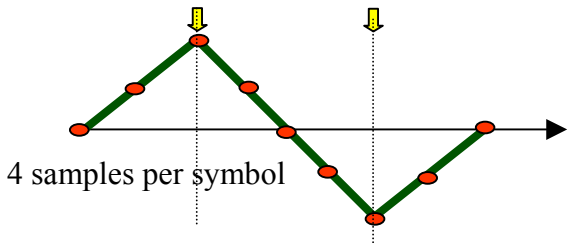
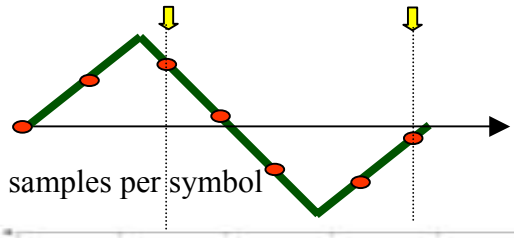
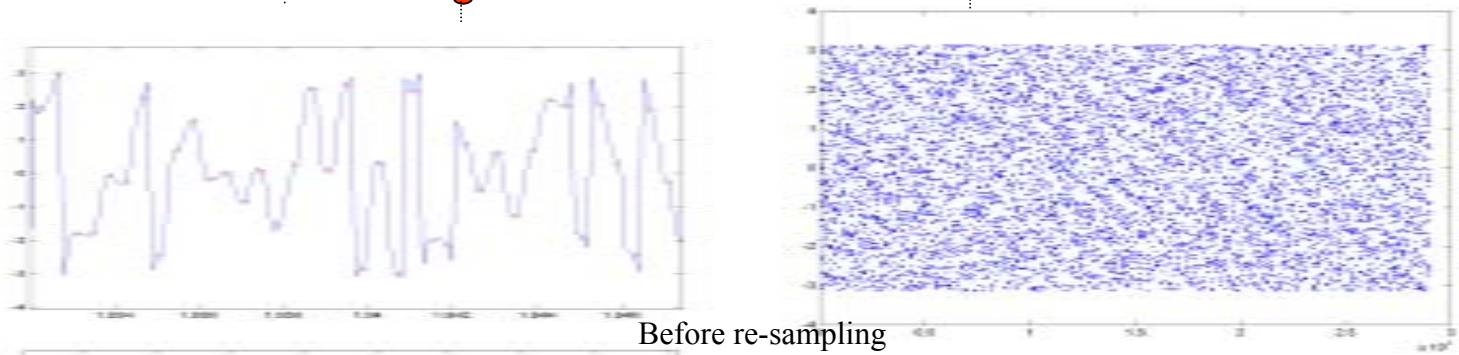
Pulse Timing

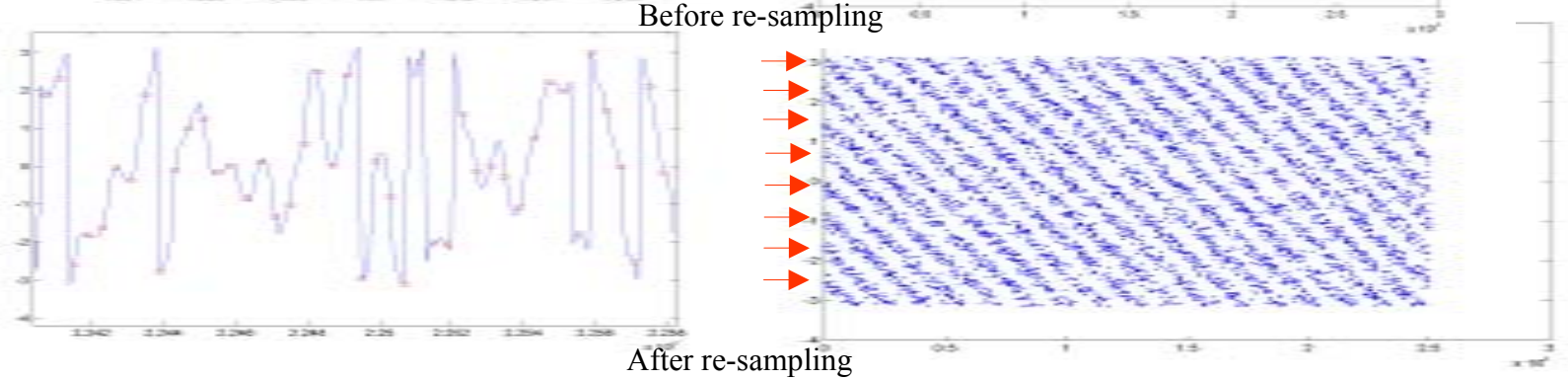
- **Re-sampling will be necessary if the symbol frequency divided by sample frequency is not an integer**
- **Error is introduced in re-sampling**







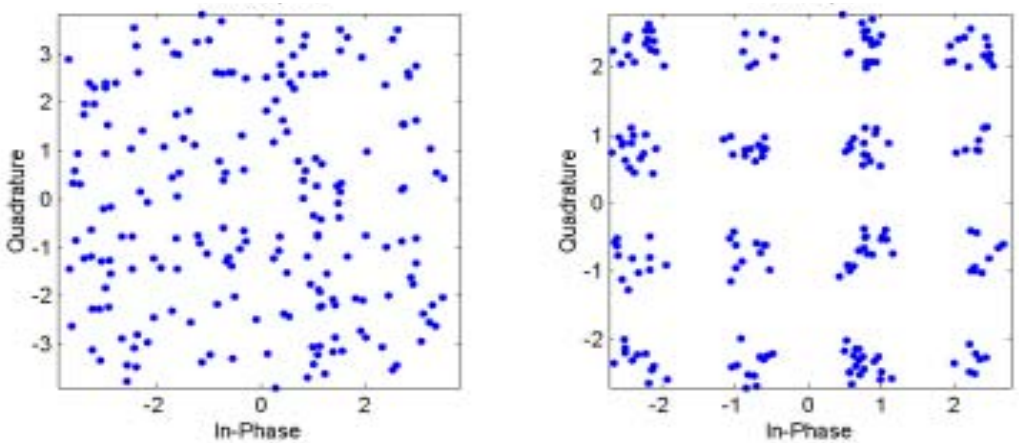
Before re-sampling



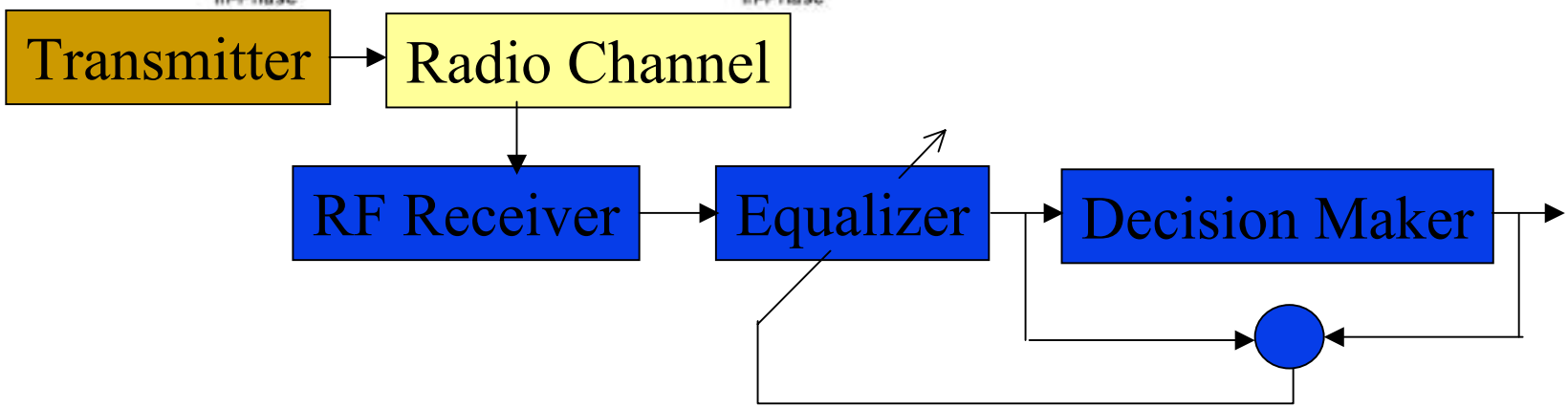
After re-sampling

Channel Distortion

Before 16-QAM After



An adaptive filter (lower figure) is used to eliminate the multiple channel distortion in wireless communication. A distorted 16-QAM signal (left figure) is blindly equalized to give a correct output (right figure) before recognition process



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Literature Search

- A web site search of “modulation recognition” gave 52,500 hits.
- More than a hundred publications on modulation recognition.
- Many GOTS and COTS products available for various applications.

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Some Well-known Approaches

Modulation feature extraction

- I-Q Analysis
- Zero-crossing
- Power-law

Modulation classification

- Pattern recognition
- Maximum likelihood

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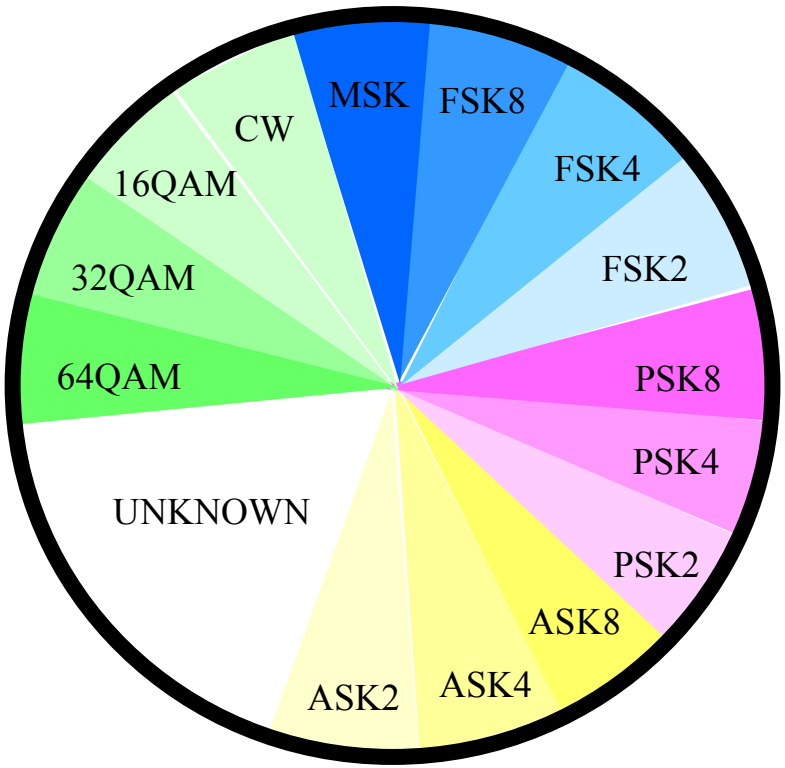
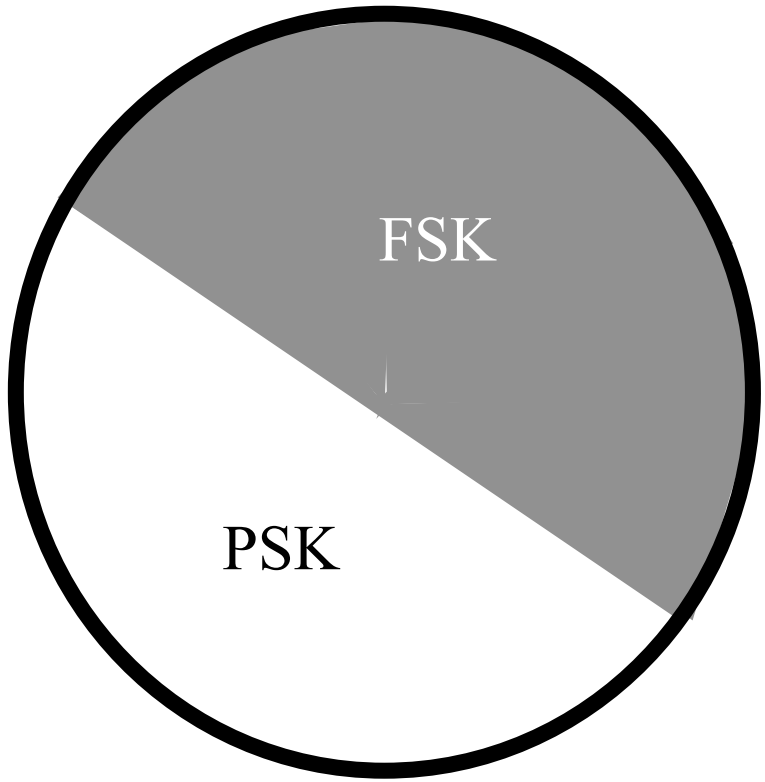
Problems in Algorithm Comparison

- Deferent modulation type
- Deferent assumption
- Deferent signal environment
- Deferent specification





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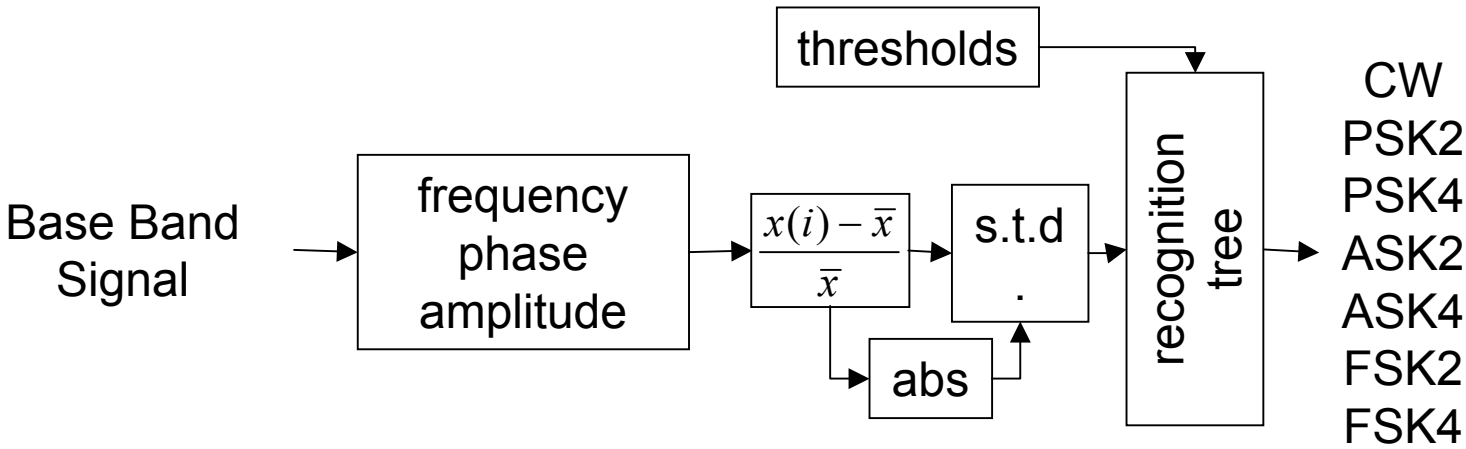
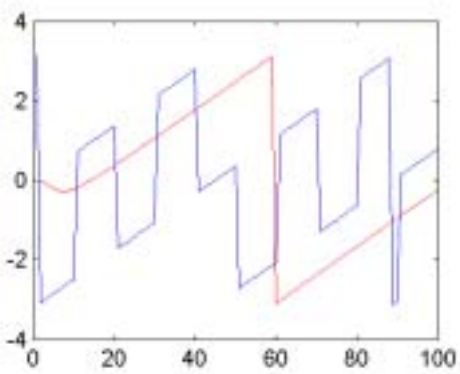
Azzouz and Nandi's Method

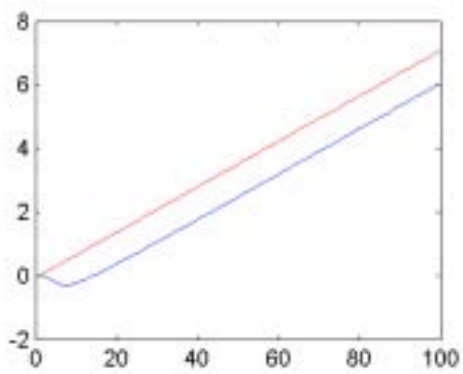
Based on signal parameter variances and variance thresholds



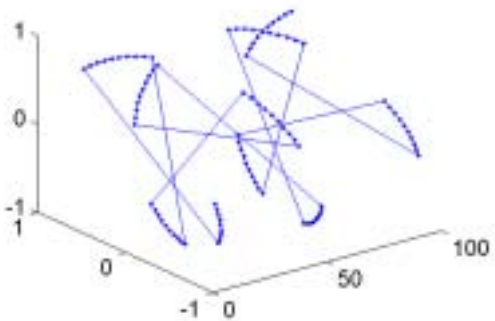
Phase Variance is affected by the Center Frequency Offset



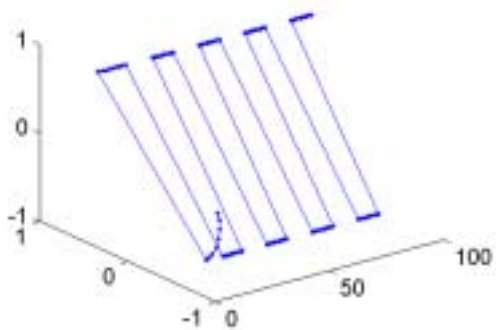
phase tracking



unwrapped phase tracking



BPSK with residual carrier



after phase tracking and compensation

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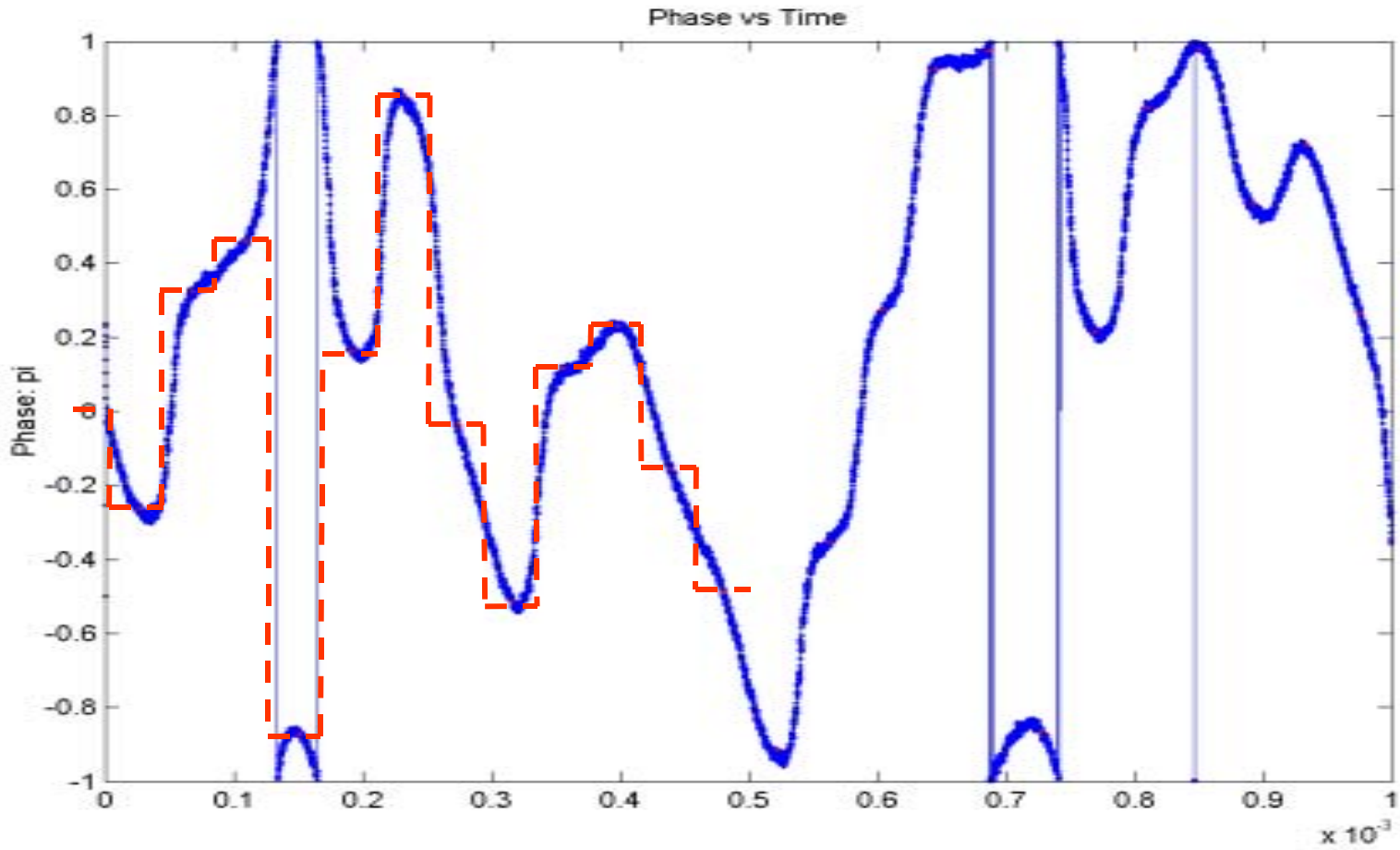
Phase Variance is Affected by Pulse Shaping ($\pi/4$ DQPSK)



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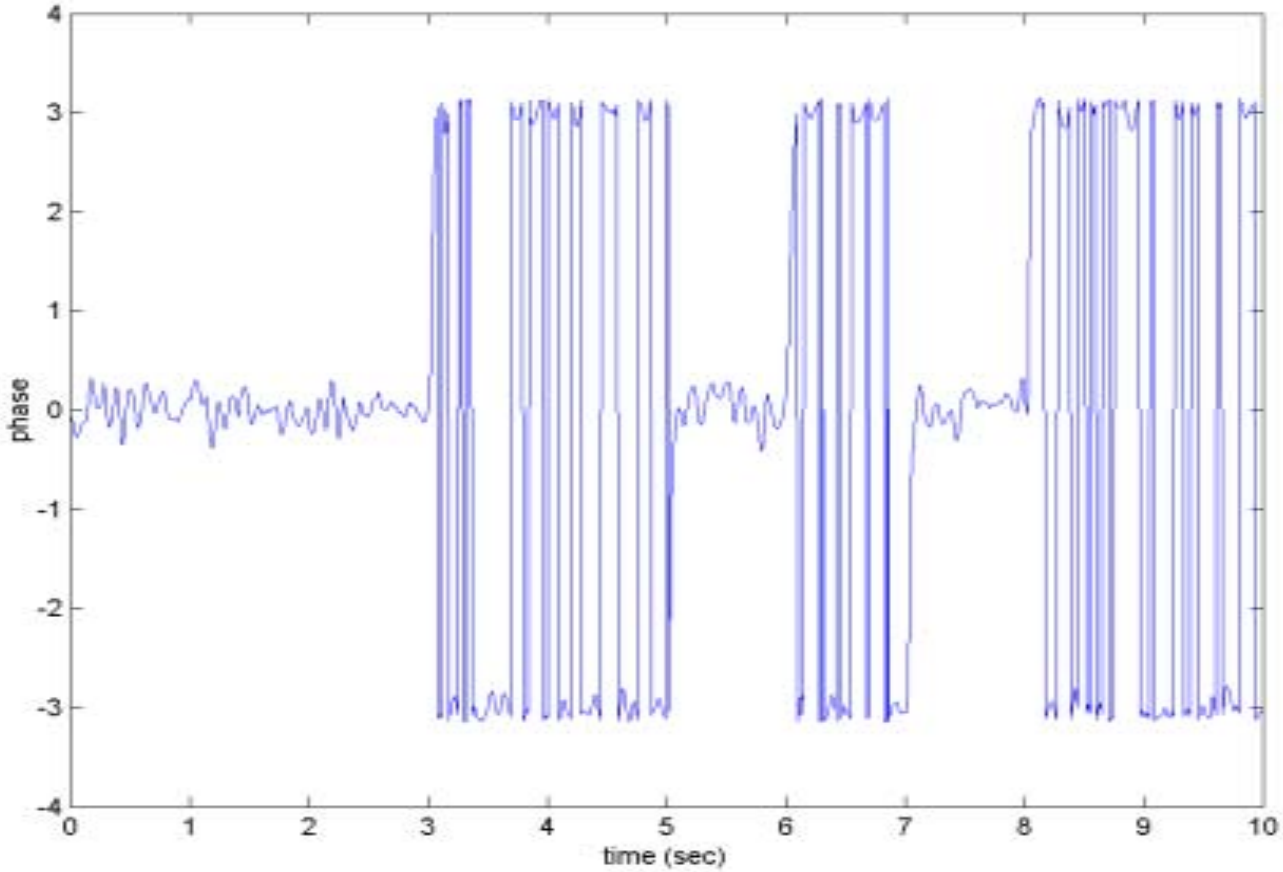
Phase Variance is Affected by Phase Wrap



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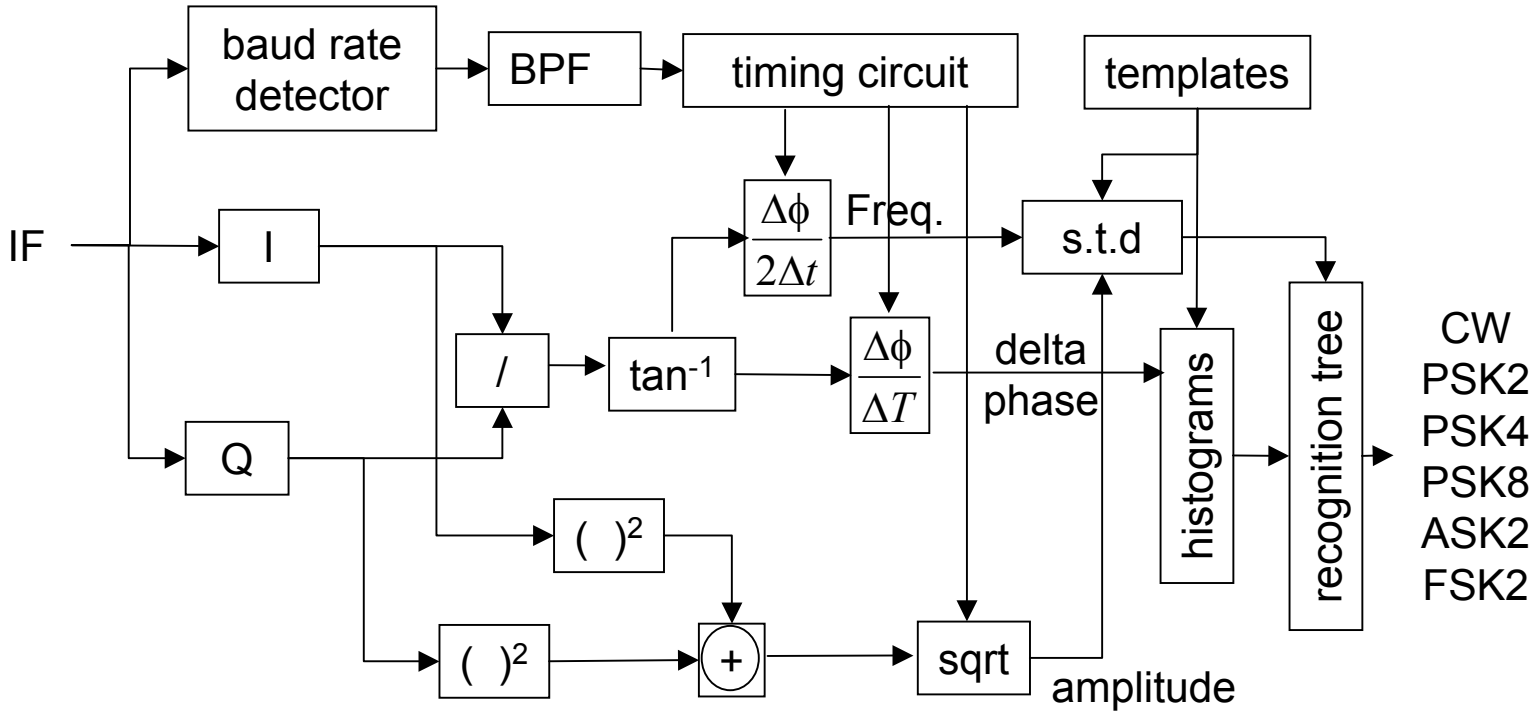
Limitation in Azzouz and Nandi

- Not robust to center frequency offset
- Not robust to pulse shaping
- Not robust to phase wrap
- Thresholds depend on SNR level
- Restricted in modulation types (2 bits)

Liedtke's Method

Based on delta-phase and histogram correlation

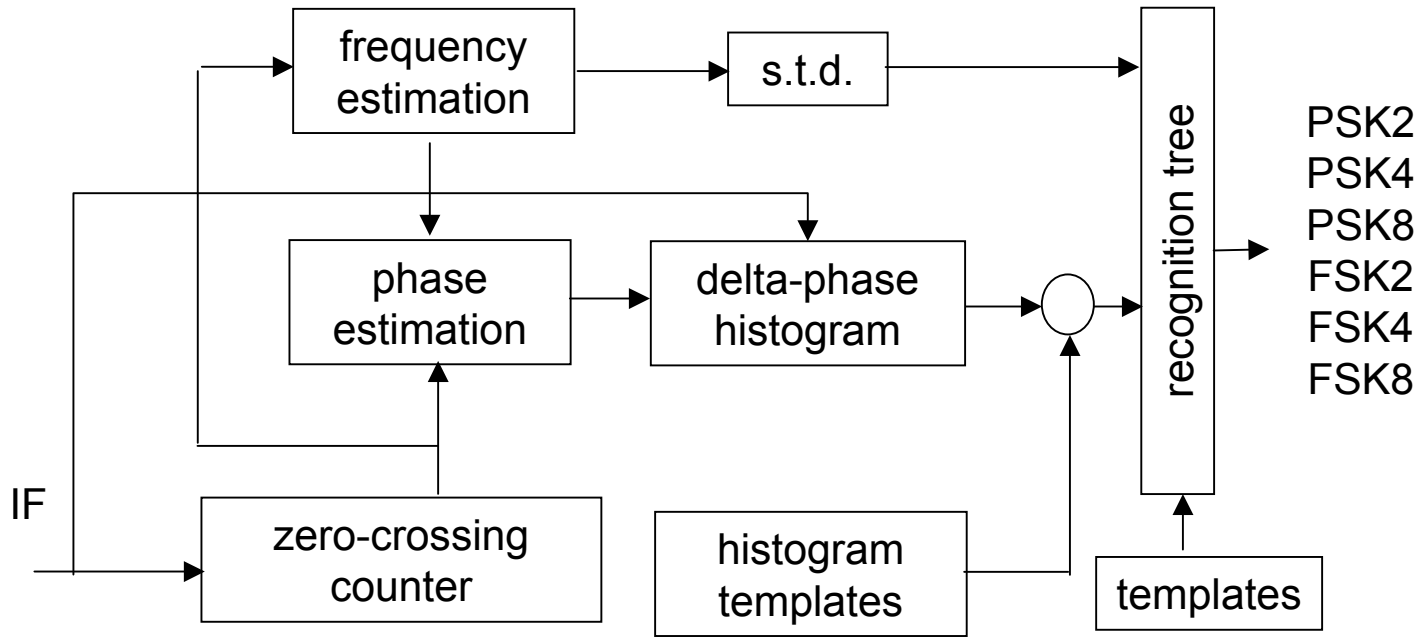


Limitation in Liedtke's Method

- Manual tuning of center frequency
- Manual tuning of the time-recovery band pass filter
- Limited in modulation types

Zero-crossing Detection Method

Based on zero-crossing phase, and delta phase histogram



Limitation in Zero-Crossing Method

- Not robust to multiple frequencies
- Need high SNR
- Need high sampling rate

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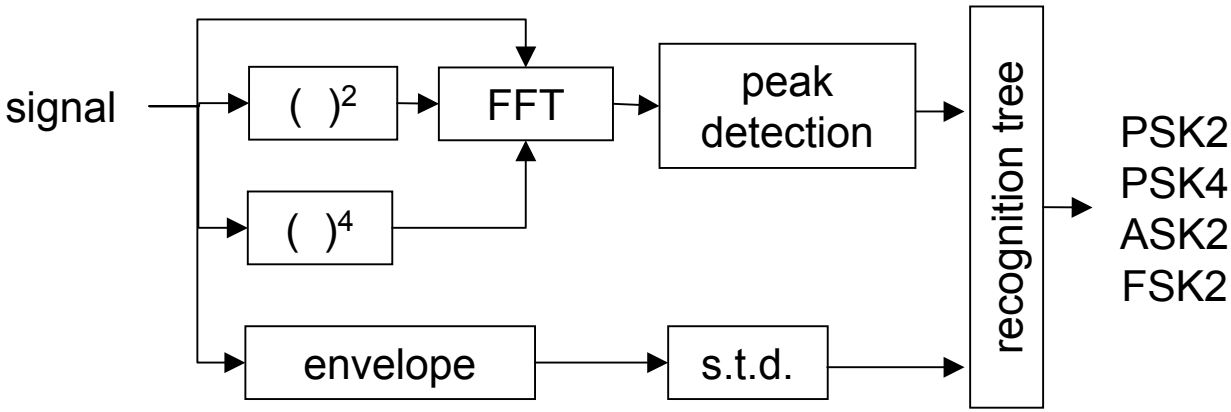
Power-Law Classification Method

Based on power spectrum analysis



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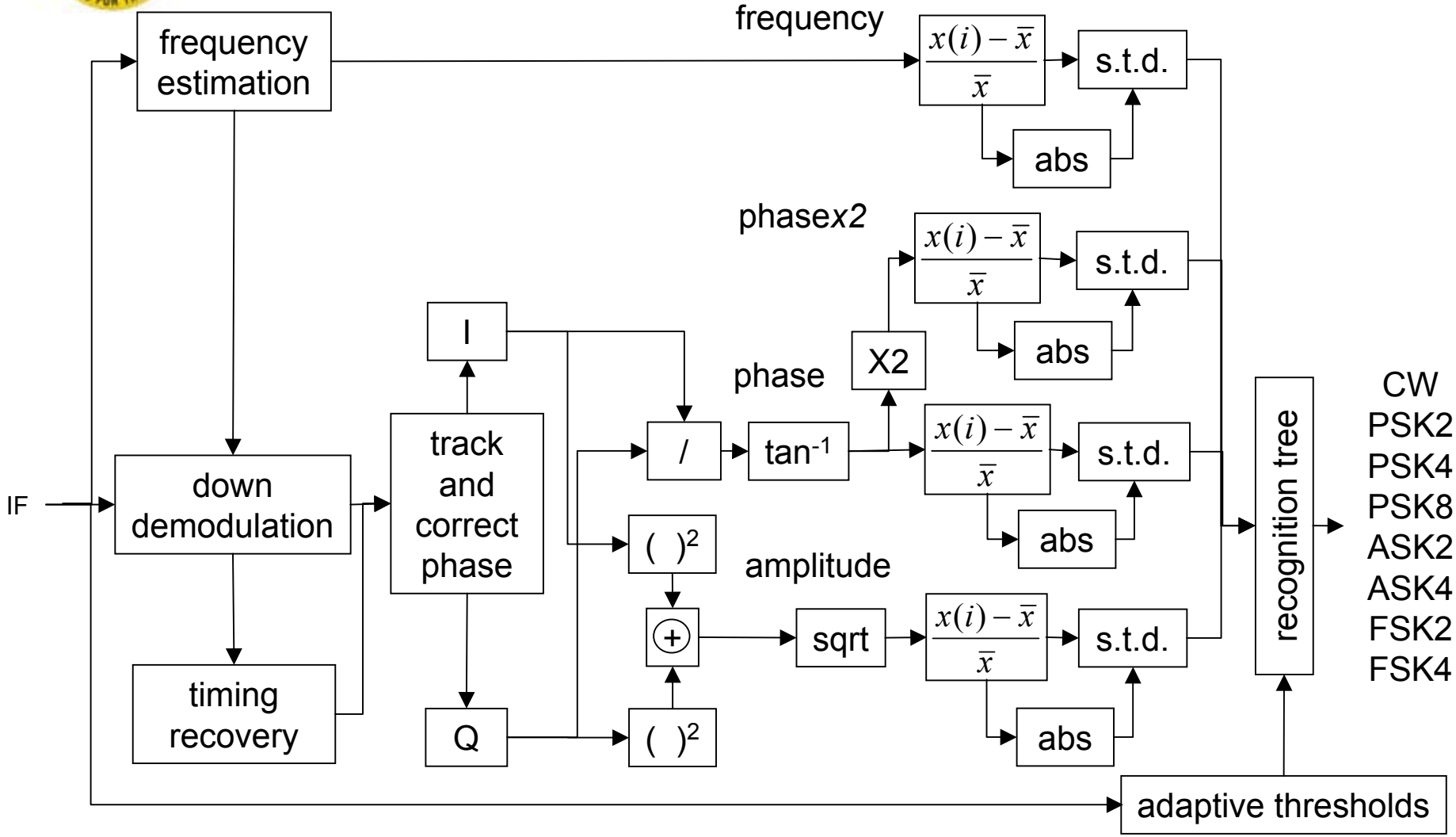
Limitation to Power-Law Method

- Need very high sampling rate
- Affected by pulse shape
- Limited in modulation types
- Noise is amplified with high order

Modified Azzouz and Nandi



Center Frequency Offset Correction

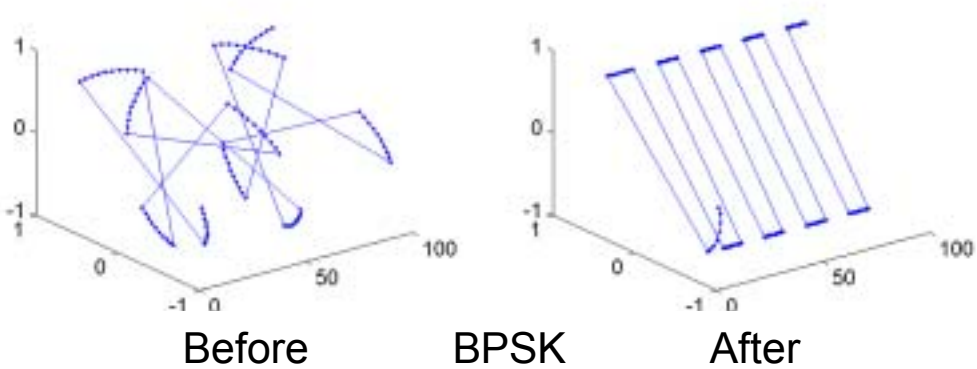
Method 1:

symbol x → $x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} real(x) \\ imag(x) \end{bmatrix}$ → $z = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = Vx$

$G(z) = z_1 z_2 (z_1^2 - z_2^2) \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$

$\gamma = \frac{|z_1 z_2 (z_1^2 - z_2^2)|}{\sqrt{2}}$

$V = \frac{I - \lambda G(z)}{\sqrt{1 + \lambda \gamma}} V$ → Estimated phase



Before BPSK After

The unwanted phase rotation (left figure) is corrected adaptively (right figure) by a modified blind carrier phase tracker (upper figure) so that the feature variation methods can be used robustly for modulation recognition

Method 2: $CFO = angle(\Sigma(y_k y^*_{k-1}) f_s/2/\pi \qquad k = 1, 2, \ldots, N$

y_k is a sample at k $\qquad$ f_s is the sampling frequency

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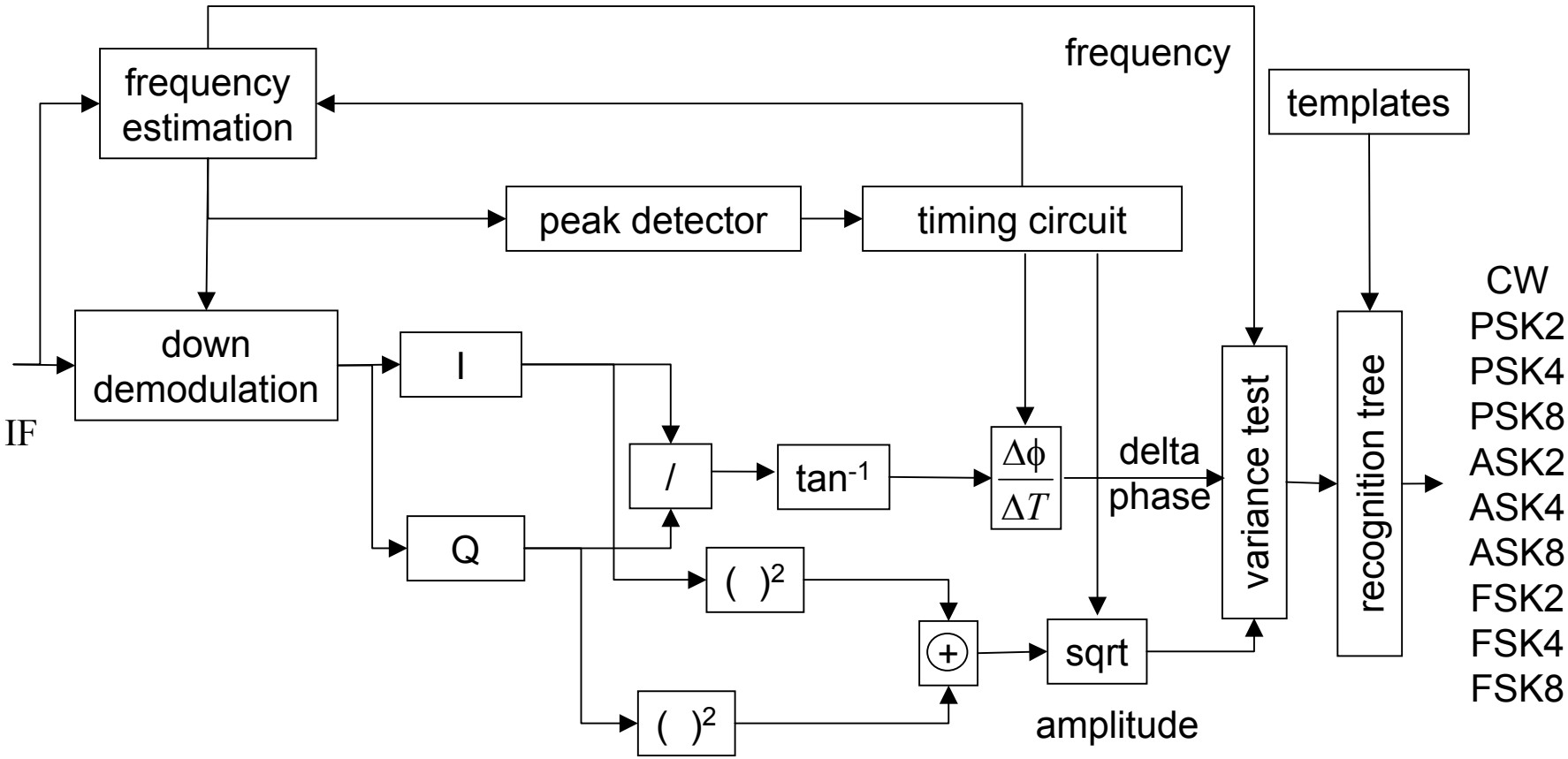
Modified Liedtke



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Summary

- There are many publications but most of them are related to base band symbol recognition
- Center frequency offset (CFO), pulse shape, timing, and channel fading can be estimated but the estimates will not be perfect
- Signal type UNKNOWN should be defined in all algorithms
- A good modulation recognition algorithm should be robust to CFO, timing error, and fading

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