Master's Thesis Defense

Applications of PAM Representation of CPM

Balachandra Kumaraswamy
February 26 2008

Committee

Dr. Erik Perrins (Chair)

Dr. James Roberts

Dr. Alexander Wyglinski

Outline

- Motivation for thesis
- Introduction
- CPM Signal Model
- SOQPSK
- PCM/FM
- SOQPSK Detectors
- PCM/FM Detectors
- Simulation Results
- Conclusion

Motivation

- Simplified SOQPSK Detectors
  - For SOQPSK detection, OQPSK-type detectors though reduces complexity, suffer 1-2 dB loss
  - PAM based detectors reduces complexity as well gives a better performance
  - Use 2-state trellis compared to 4-states in previous approaches
- Simplified PCM/FM Detectors
  - PCM/FM is also a type of CPM
  - Ibrahim had developed simplified trellis-based detectors for Bluetooth.
  - Since Bluetooth and PCM/FM share a number of similarities we decided to combine Bluetooth algorithms and PCM/FM.

Publications

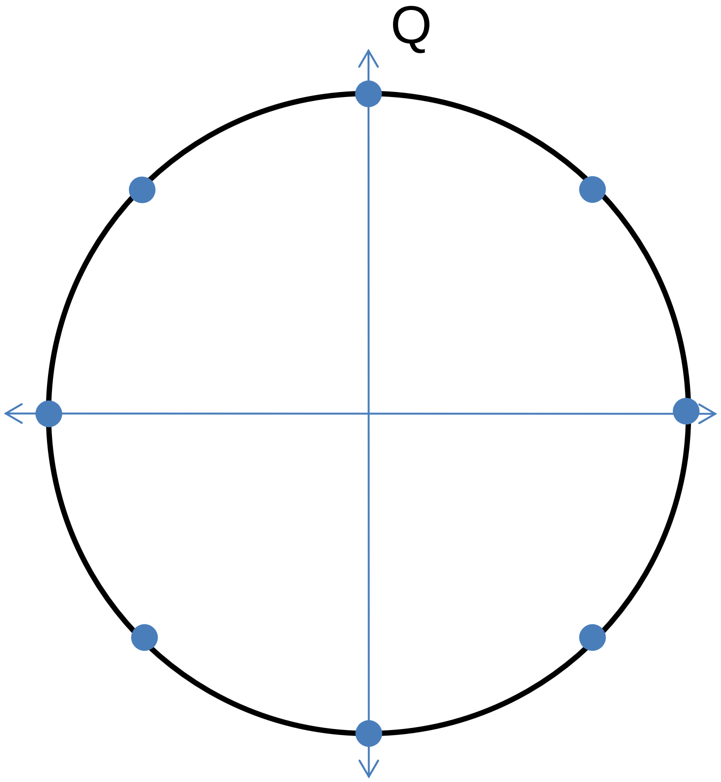
- Balachandra Kumaraswamy and E. Perrins, "Simplified 2-State detectors for SOQPSK", *Military Communicatios (MILCOM) conference*, Orlando, Florida, October, 2007.
- Balachandra Kumaraswamy and E. Perrins, "Simplified 2-State detectors for SOQPSK-MIL and SOQPSK-TG", *Proceedings of the International Telemetering Conference (ITC),* Las Vegas, NV, October, 2007.

So What ??

- SOQPSK
  - OQPSK type detector 1-2 dB loss
  - CPM overcomes this problem
  - For M-ary CPM with modulation index *h=k/p,* the number of trellis states is $p \cdot M^{L-1}$ and M^L matched filters (MFs)
  - PAM representation reduces the complexity of the receiver
- PCM/FM
  - Optimum detector has 20 states and 8 matched filters, hence complex receiver design
  - Complexity of the receiver reduced using PAM

Introduction

- Continuous Phase Modulation(CPM)
  - ➢Constant envelope
  - ➢Memory
- Advantages
  - ➢Simple transmitter
  - ➢Power and Spectral efficiency
  - ➢High Detection efficiency
  - ➢Good for non-linear power amplifiers
- Applications
  - ➢ Aeronautical Telemetry
  - ➢ Bluetooth
  - ➢ Deep-space Communications
  - ➢ Satellite Communications
  - ➢ Wireless Modems



Introduction

- Advantages of CPM
  - Highly Bandwidth efficient
  - Constant Signal envelope
- Both SOQPSK and PCM/FM have been deployed into the Aeronautical Telemetry standard.
- Trellis-based detectors give better performance where as increases the complexity.
- PAM Decomposition reduces the complexity of implementation.

CPM Signal Model

The complex-baseband representation of SOQPSK as a form of CPM is

$$s(t;\boldsymbol{\alpha}) \triangleq \exp\{j\phi(t;\boldsymbol{\alpha})\}$$

where phase is a pulse train of the form

$$\phi(t;\boldsymbol{\alpha}) \triangleq 2\pi h \sum_i \alpha_i q(t-iT)$$

α_i is the transmitted symbol, T is the duration of each symbol and *h* is the modulation index. *q*(t) is the phase pulse and *f*(t) is the frequency pulse with area ½ and duration LT.

Frequency and Phase Pulse for SOQPSK-TG

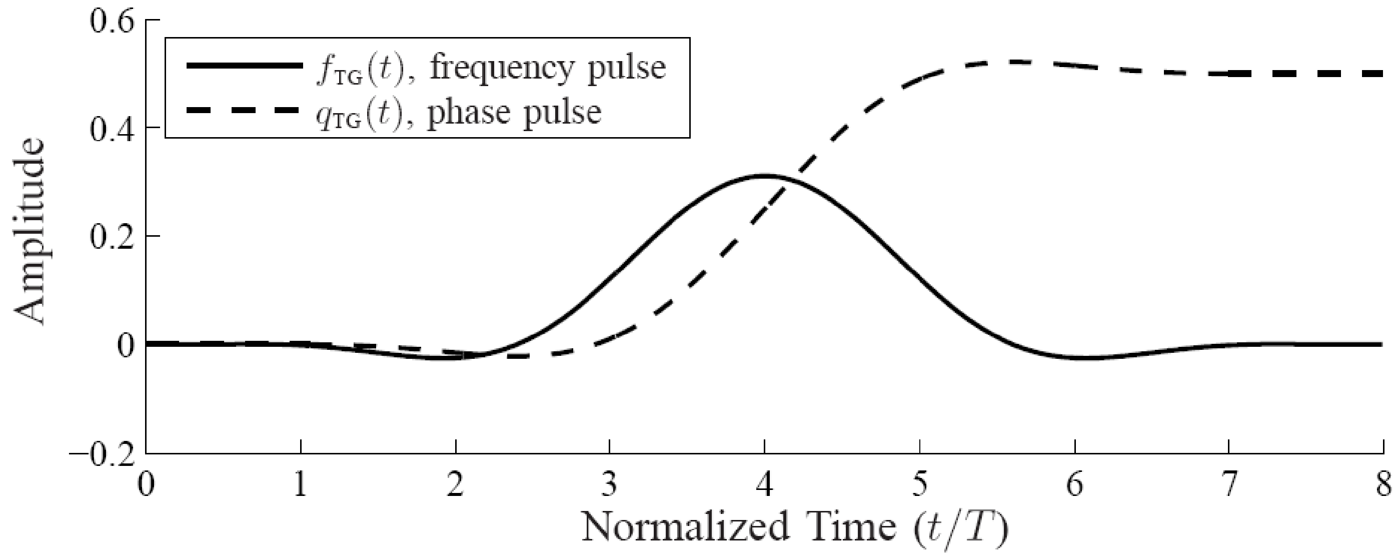
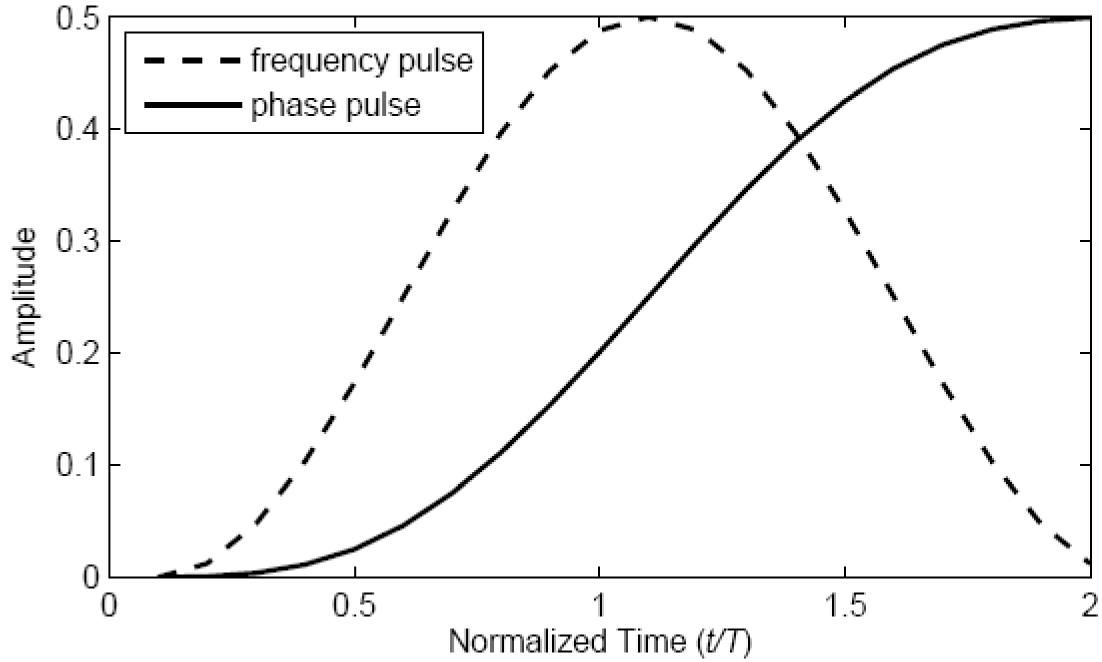
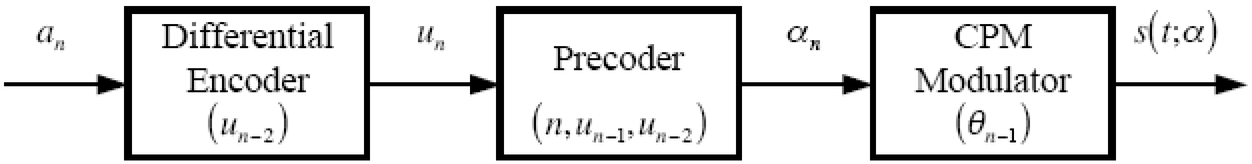


Figure 2.1. The length-8T frequency and phase pulses for SOQPSK-TG.

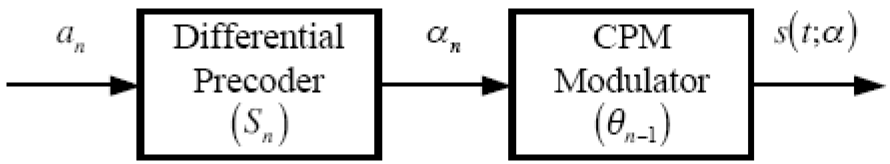
Frequency and Phase Pulse for PCM/FM



SOQPSK Precoder



4-state precoder



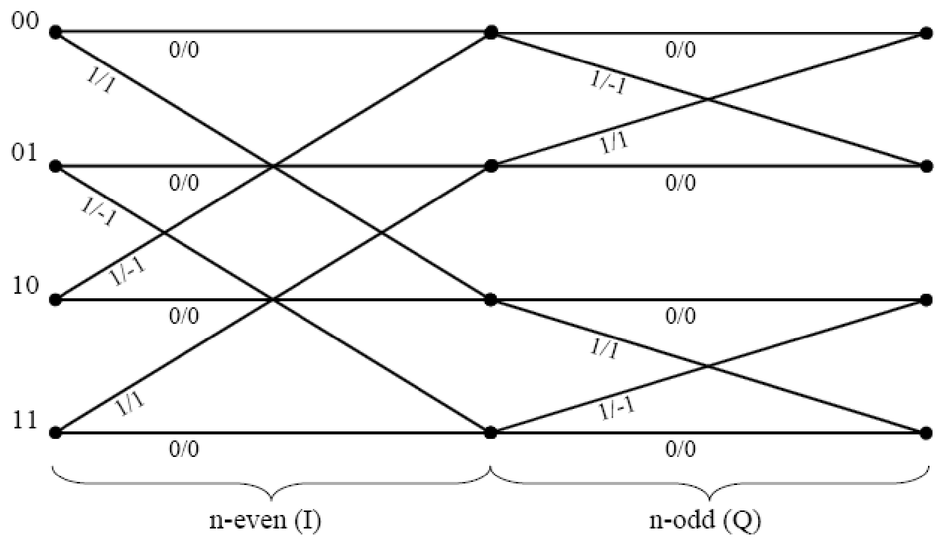
2-state precoder

The transmitted symbols α using the following precoding operations

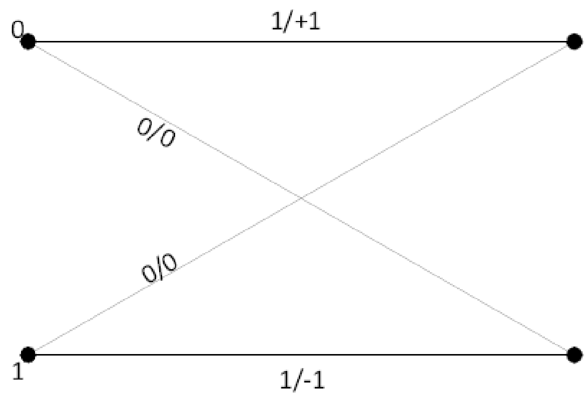
1) $u_i = a_i \oplus u_{i-2}, \qquad a_i, u_i \in \{0,1\}$

2) $\alpha_i(u) = (-1)^{i+1}(2u_{i-1} - 1)(u_i - u_{i-2})$

Trellis



4-state trellis



2-state trellis

SOQPSK Detector

•Received signal model r(t) = s(t) + n(t), where n(t) is AWGN with psd N_0.

• Transmitted signal s(t) has memory, we use Viterbi Algorithm (VA) for Maximum Likelihood Sequence Detection (MLSD).

• Cumulative metric $\lambda_n(\tilde{S}_n)$ is maintained for each state.

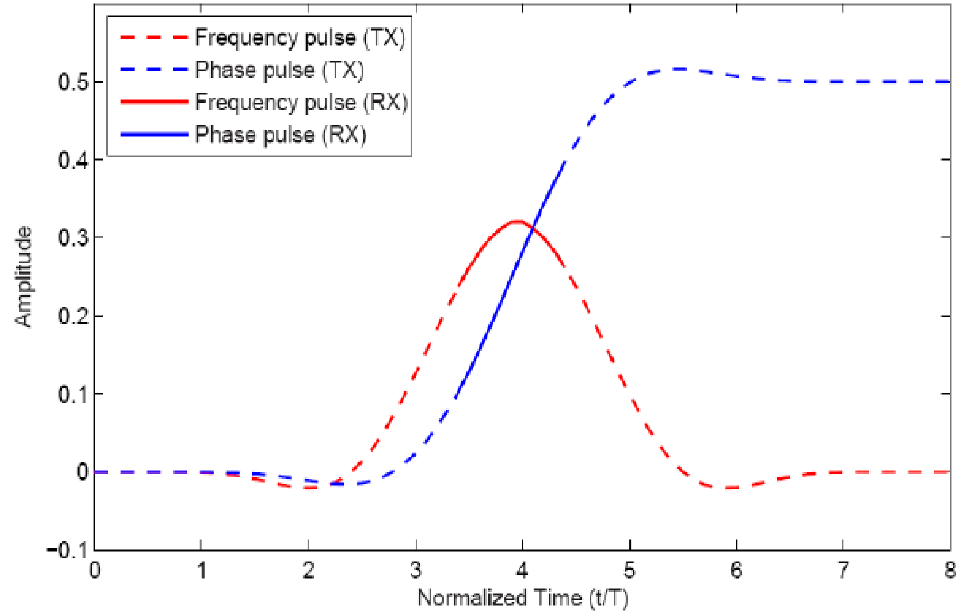
• The branch metric is updated using

$$\lambda_{n+1}(\tilde{E}_n) = \lambda_n(\tilde{S}_n) + z(n, [\tilde{a}_n, \tilde{S}_n])$$

where $z(n, [\tilde{a}_n, \tilde{S}_n])$ is the branch metric increment.

Pulse Truncation

- For SOQPSK-TG we have truncated frequency pulse to a duration of one symbol time at the detector.
- Trellis states reduced from 512 states to 4 states.



Branch metric increment for PT is given by

$$z_{\mathrm{PT}}(n, [\tilde{a}_n, \tilde{S}_n]) \triangleq \mathrm{Re}\left[e^{-j\tilde{\theta}_{n-1}} \int_{nT}^{(n+1)T} r(t+(L-1)T/2) e^{-j2\pi h \tilde{\alpha}_n q_{\mathrm{PT}}(t-nT)} dt \right]$$

PAM Representation of CPM Signal

Laurent showed the CPM can be represented as a superposition of PAM waveforms

$$s(t;\alpha) = \sum_n \sum_{k=0}^{Q-1} b_k[n] c_k(t-nT), \qquad Q = 2^{L-1}$$

where $b_k[n]$ are pseudo-symbols.

Also Perrins and Rice showed that ternary CPM waveforms can be represented using PAM decomposition as

$$s(t;\boldsymbol{\alpha}) = \sum_n \sum_{k=0}^{R-1} v_k[n] g_k(t-nT), \qquad R = 2 \cdot 3^{L-1}$$

PAM based detector

- For SOQPSK the PAM equation can be reduced to

$$s(t;\boldsymbol{\alpha}) = \sum_{n}\sum_{k=0}^{1} b_k[n]c_k(t-nT)$$

- Branch metric increment for PAM

$$z_{\mathrm{PAM}}(n,[\tilde{a}_n,\tilde{S}_n]) = \mathrm{Re}\left[e^{-j\tilde{\theta}_{n-1}}\sum_{k=0}^{1} y_k(n)[\beta_k(\tilde{\alpha}_n)]^*\right]$$

- Sampled MF output

$$y_k(n) = \int_{nT}^{(n+L+1-k)T} r(t)g_k(t-nT)\,dt$$

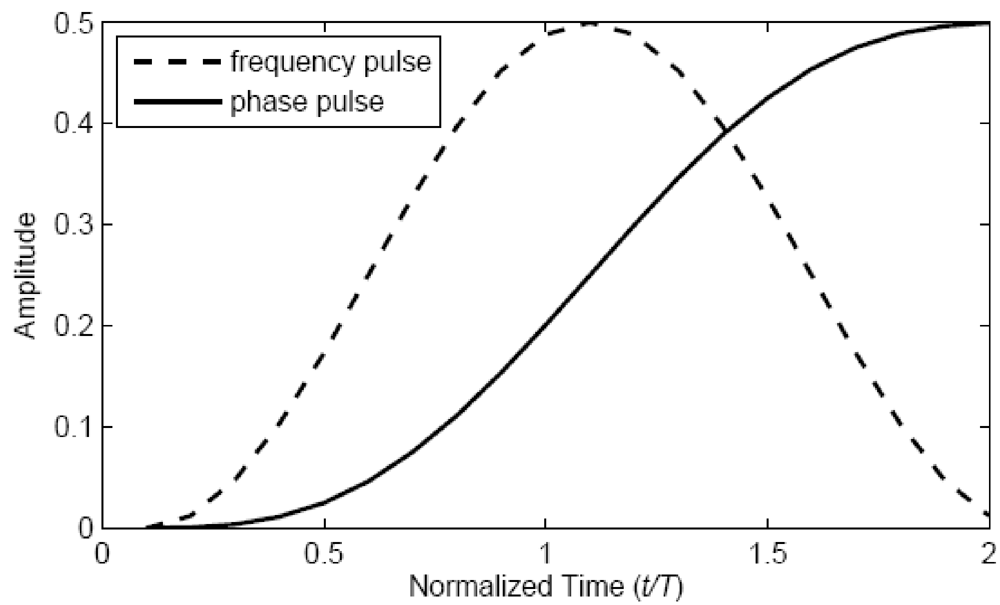
2-state detector

- One-One correspondence between the trellis state and phase does not exist.
- Decision feedback to overcome this problem
- Cumulative phase $\hat{\theta}_{n-1}(\tilde{S}_n)$ is maintained for each state.
- The cumulative phase is updated using

$$\hat{\theta}_n(\tilde{E}_n) = \left[\hat{\theta}_{n-1}(\tilde{S}_n) + \pi h \hat{\alpha}_n(\tilde{E}_n)\right] \bmod 2\pi$$

PCM/FM

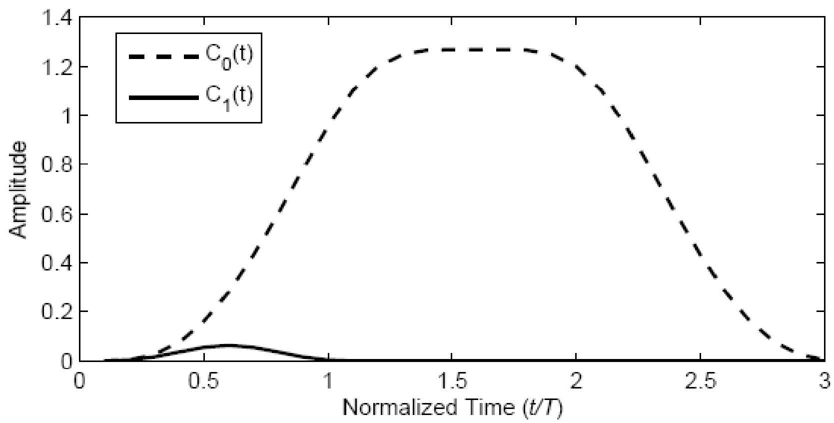
- Pulse Code Modulation/Frequency Modulation (PCM/FM) is a form of CPM with modulation index $h = 7/10$, M = 2 and 2RC.
- Frequency and Phase pulse

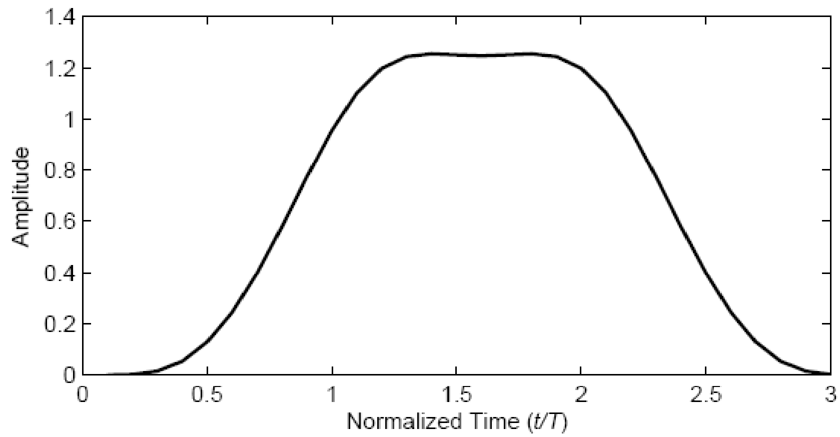


PCM/FM detection

- Equivalent PAM signal representation for PCM/FM with $L = 2$

$$s(t) = \sum_n \sum_{k=0}^{1} b_k[n] c_k(t - nT)$$



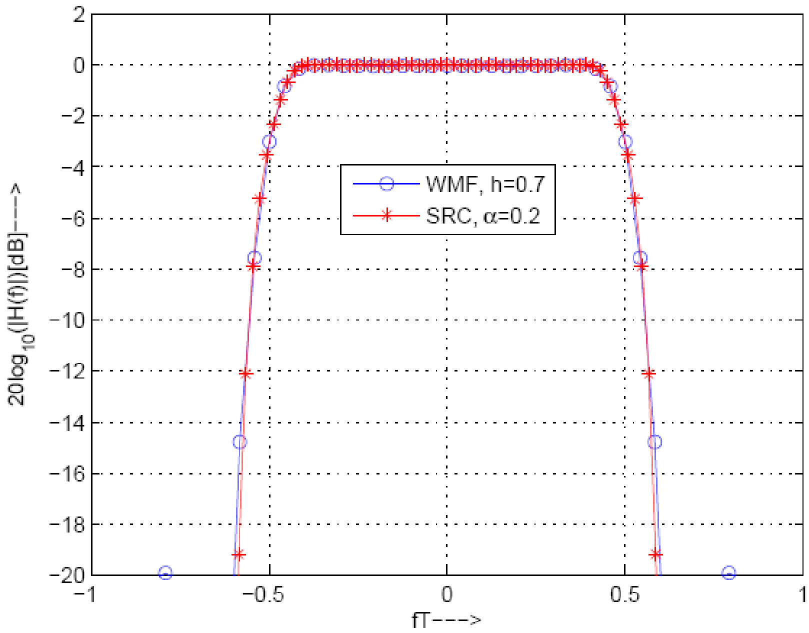


Using the main PAM pulse p(t) the equivalent linear model for CPM can be represented as

$$s(t) \simeq \sum_n b[n] p(t - nT)$$

PCM/FM Detection

- The received signal r(t) = s(t) + n(t).
- The magnitude frequency response of whitening match filter (WMF) and square root cosine (SRC) is shown.
- Here we discuss two approache using WMF as well as SRC.



PCM/FM Detection using SRC

- The received signal after filtered using p(t) and sampled at symbol-rate

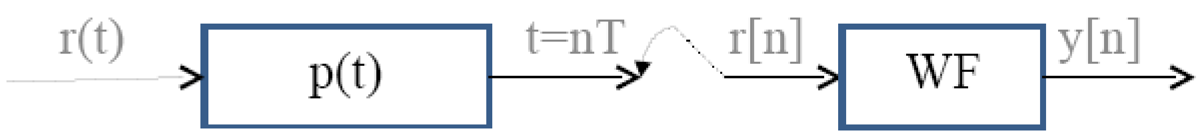
$$r[n] = r(t) * p(t)|_{t=nT} = \sum_{l=0}^{q_{h_c}} h_c[l]b[n-l] + w[n]$$

where $h_c[n] = p(t) * p(t)|_{t=nT}, \quad 0 \leq n \leq q_{h_c}$ of order q_{h_c} .

The noise n[k] is made white passing through whitening filter (WF)

$$WF(n) = \frac{1}{31.5336}\left[\frac{1}{1.8226}(-0.5487)^{(n)}\frac{1}{33.3562}(-0.03)^{(n)}\right]$$

where -8≤n≤0. The received signal model can be represented as



$$y[n] = r[n] * WF[n] = \sum_{l=0}^{q_{h0}} h_0[l]b[n-l] + v[n] \qquad h_0[n] = h_c[n] * WF[n]$$

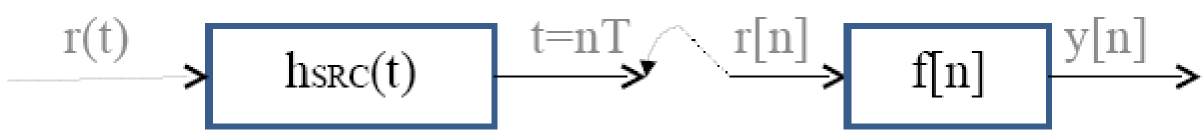
PCM/FM Detection

- The received signal after filtered using $h_{SRC}(t)$ and sampled at symbol-rate

$$r[n] = r(t) * h_{\text{SRC}}(t)|_{t=nT} = \sum_{l=0}^{q_{h_c}} h_c[l]b[n-l] + w[n]$$

where $h_c[n] = p(t) * h_{\text{SRC}}(t)|_{t=nT}, 0 \leq n \leq q_{h_c}$ of order q_{h_c}

The received signal model can be represented as



The filtered received sequence is given by

$$y[n] = r[n] * f[n]$$

VA for PCM/FM

The trellis state can be defined as $\tilde{\mathbf{a}}[n] = [\tilde{a}[n] ... \tilde{a}[n - n_s + 1]]$ of n_s hypothetical symbols

- We also have vector $\hat{\mathbf{b}}[n] = [\hat{b}[n - n_s] ... \hat{b}[n - q_{h_0} + 1]]$ associated with each state.

- The VA is given as $$\lambda(\tilde{\mathbf{a}}[n-1], \tilde{a}[n]) = \left| d[n] - \sum_{l=0}^{n_s} h_0[l] \tilde{b}[n-l] \right|^2$$

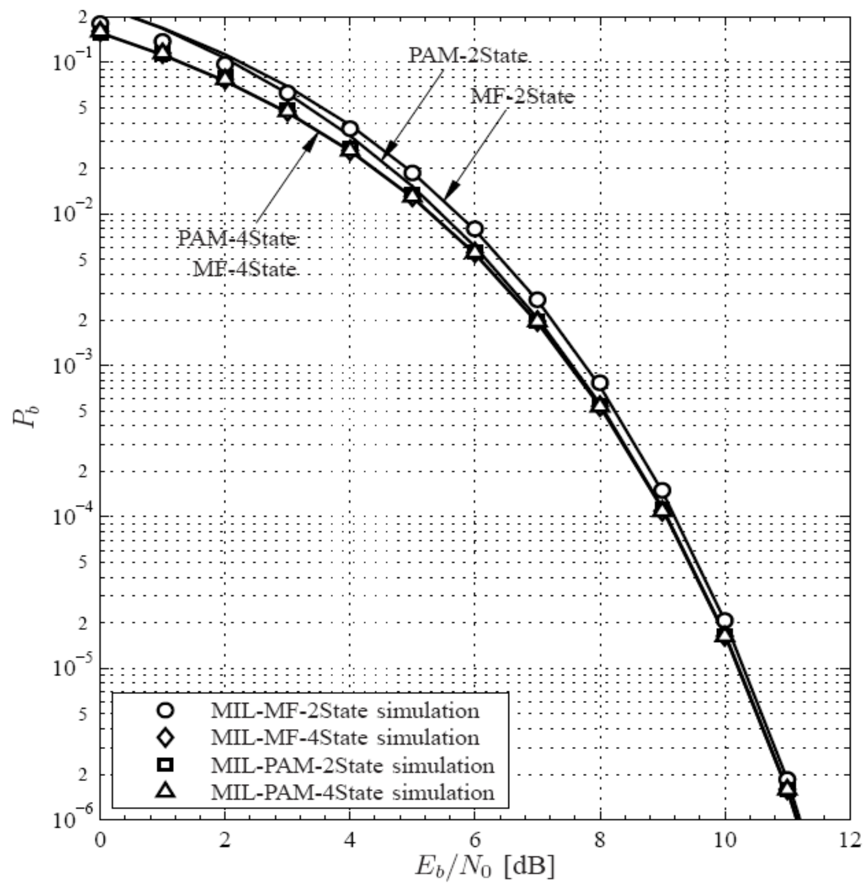
where $$d[n] = y[n] - \sum_{l=n_s+1}^{q_{h_0}} h_0[l] \hat{b}[n-l]$$

and $$\tilde{b}[n-l] = \hat{b}[n - n_s - 1] \exp\left(j\pi h \sum_{k=n-n_s}^{n-1} \tilde{a}[k] \right)$$

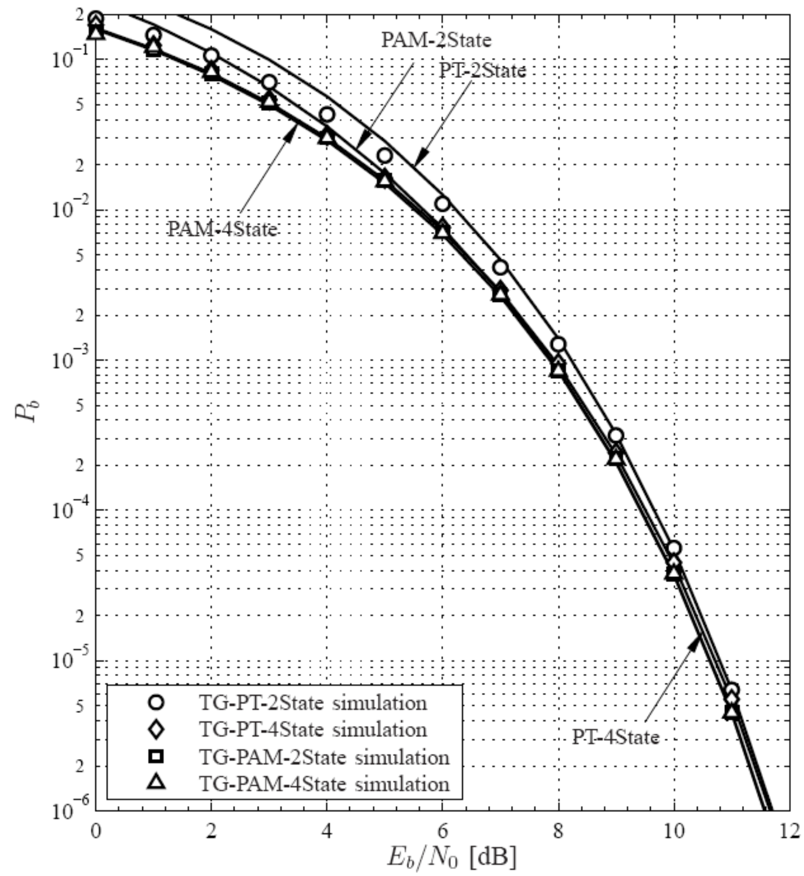
In case of $n_s = 0$ we have the decision rule as

$$\hat{a}[n] = \arg\max \tilde{a}[n] \ \mathrm{Re}\left\{ d^*[n] \hat{b}[n-1] e^{j\pi h \tilde{a}[k]} \right\}$$

Simulation Results



SOQPSK-MIL BER



SOQPSK-TG

BER

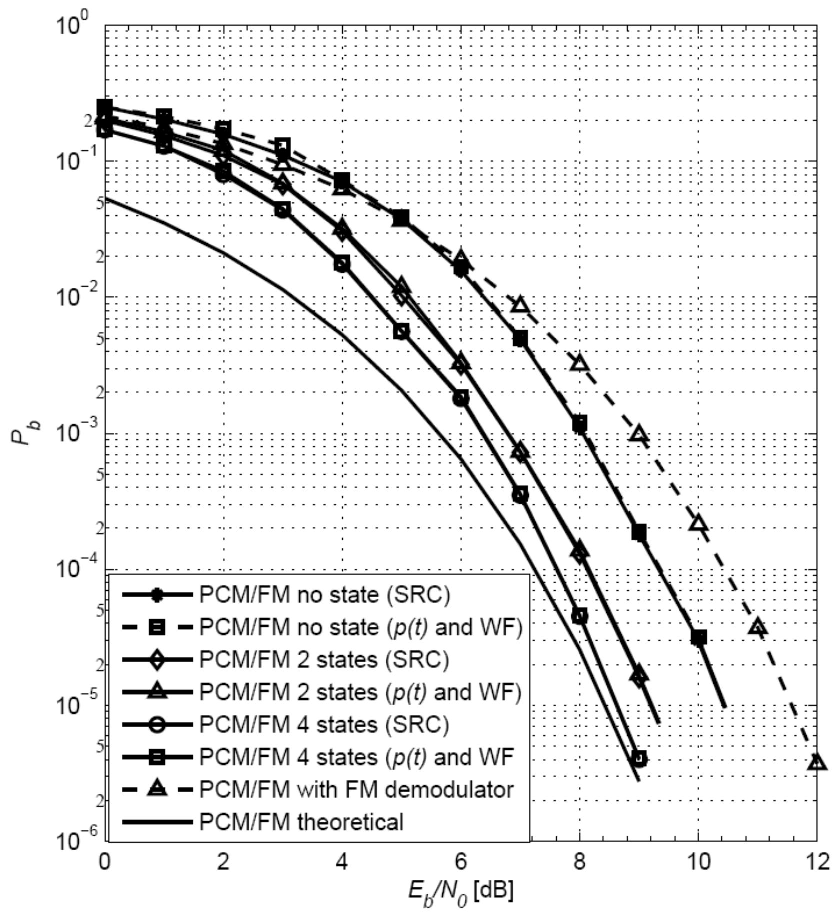
INFORMATION & TELECOMMUNICATION TECHNOLOGY CENTER
The University of Kansas

Simulation Results contd …

- 2-state detectors matches the performance of that of 4-state detectors for higher values of E_b/N_0 .
- PAM technique has an advantage of 0.1 dB compared to PT.

Simulation Results contd…

- The Probability of bit-error is given by $P_b = Q\left(\sqrt{d^2 \frac{E_b}{N_0}}\right)$ where $d^2 = 2.6.$
- 0-state detectors reduces complexity but loses 2 dB
- 2-state detectors gives a better performance within 1dB of the optimal detector.
- 4-state detectors gives a performance within 0.4 dB of the optimal detector.



Conclusion

- Successfully developed PAM based reduced complexity detectors for SOQPSK and PCM/FM
- In case of SOQPSK, 2-state PAM based detectors gives a performance comparable to that of optimal
- 4-state PAM detectors for PCM/FM gives a near optimal performance.

Thank You

Questions ??