Performance Of SOQPSK And Multi-h CPM In The Presence Of Adjacent Channel Interference

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Outline

• Waveform definitions (briefly!)
• Spectral characterizations of telemetry waveforms
• Effects of IF filtering on link performance
• Aggregate effect of adjacent channel interference
Why These Waveforms?

• Advanced Range Telemetry (ARTM) Program
  – Before ARTM (Tier 0?)
    • PCM/FM
    • “Legacy” waveform for telemetry
  – ARTM Tier 1
    • Proprietary Feher-patented FQPSK-B, Revision A1
    • SOQPSK is
      – Comparable in performance to FQPSK-B, Revision A1
      – Non-proprietary
  – ARTM Tier 2
    • Multi-h CPM (M=4, L=3RC, h1 = 4/16, h2 = 5/16)

• SOQPSK and Multi-h CPM are continuous phase modulations
CPM Waveforms

\[
s(t) = \sqrt{2E/T} \cos[\pi f_0 t + \phi(t, \alpha) + \phi_0]
\]

\[
\phi(t, \alpha) = 2\pi h \int_{-\infty}^{t} \sum_{i=-\infty}^{t} \alpha_i g(t - iT) d\tau \quad -\infty < t < +\infty
\]

- Constant envelope, information is carried entirely in the phase
- PSD and BER can be “traded” by
  - Varying \( h \), modulation index
  - Changing \( g(t) \), the frequency pulse shape
- FQPSK-B (Revision A1) is not truly a CPM waveform because of its AM component
Offset QPSK Variations

- Unshaped
- Rectangular
  - MIL-STD-188-18x
- "Shaped"
  - Arbitrary g(t)
SOQPSK

- MIL-STD-188-181, -182
- Continuous phase modulation, $h = 1/4$, $g(t) = \text{rectangle}$
- Constant envelope
- Three rates of phase change: $0, +\Delta f, -\Delta f$
Definition of SOQPSK-A, -B

\[ g(t) = r(t) \ast w(t), \text{ where} \]

\[ r(t) = \frac{A \cos(\pi B \psi T)}{1 - 4(\rho B \psi T)^2} \ast \frac{\sin(\pi B \psi T)}{(\pi B \psi T)} \]

\[ w(t) = \begin{cases} 
1, & \text{for } |\psi T| < T \\
\frac{1}{2} + \frac{1}{2} \cos \left( \frac{\pi (|\psi T| - T_1)}{T_2} \right), & \text{for } T_1 < |\psi T| < T_1 + T_2 \\
0, & \text{for } |\psi T| > T_1 + T_2 
\end{cases} \]
Frequency Pulse Shape, $g(t)$

![Frequency Pulse](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SOQPSK-A</th>
<th>SOQPSK-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>$B$</td>
<td>1.35</td>
<td>1.45</td>
</tr>
<tr>
<td>$T_1$</td>
<td>1.4</td>
<td>2.8</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Power Spectral Density
SOQPSK-A Eye Pattern
SOQPSK-B Eye Pattern
Definition of Multi-h CPM

\[ s(t) = \sqrt{2E/T} \cos \left[ 2\pi f_o t + \phi(t, \alpha) + \phi_o \right] \]

Modulating Phase using Frequency Pulses

\[ \phi(t, \alpha) = 2\pi h \int_{-\infty}^{t} \sum_{i=\infty}^{t} \alpha_i g(\tau - iT) d\tau \quad -\infty < t < +\infty \]

Modulating Phase using Phase Pulses

\[ \phi(t, \alpha) = 2\pi h \sum_{i=\infty}^{\infty} \alpha_i q(\tau - iT) \]
Key CPM Parameters

- M – Order of Modulation (2-ary, 4-ary, etc.)
- g(t) - Frequency Pulse (Rectangular, Raised Cosine, etc.)
- L – Length of Frequency Pulse
- h – Modulation Index

- Results here are for M=4, L=3RC, h1 = 4/16, h2 = 5/16
Frequency Pulse and Phase Tree
PSD Comparison

Telemetry PSDs

Advanced Range Telemetry (ARTM) Lab
Edwards Air Force Base
HP 8566B
Resolution Bandwidth = 3 kHz
Video Bandwidth = 10 kHz
Data Rate = 1.0 Mbps

-100 -90 -80 -70 -60 -50 -40 -30 -20 -10

Frequency [Bit Rates]}

dBc in 3 kHz Bandwidth

-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0

PCM/FM
Multi-h CPM
SOQPSK-A
FQPSK-B
SOQPSK-B
SOQPSK-A, NLA
SOQPSK-B, NLA
FQPSK-B, NLA
ARTM Tier II (Multi-h CPM)
PSD is Half the Story

- Overall spectral efficiency is determined by spacing between channels
- Receiver selectivity affects channel spacing
- A valid comparison must account for both transmitted spectrum and “tolerable” receiver filtering
- Not all modulations are equally “tolerant” of IF filtering
SOQPSK-B
Narrow IF
Experimental Setup
9 Mbps SOQPSK-A, Multichannel
9 Mbps Multi-h CPM, Multichannel
Summary

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Channel spacing for 1 dB loss at I/S ratio = 0 dB</th>
<th>Channel spacing for 1 dB loss at I/S ratio = 10 dB</th>
<th>Channel spacing for 1 dB loss at I/S ratio = 20 dB</th>
<th>Eb/N0 for BER = 1.0e-5, with I/S ratio = 20 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOQPSK-A</td>
<td>-</td>
<td>-</td>
<td>1.11 bit rates</td>
<td>14.5 dB</td>
</tr>
<tr>
<td>SOQPSK-B</td>
<td>1.0 bit rates</td>
<td>1.4 bit rates</td>
<td>1.50 bit rates</td>
<td>12.0 dB</td>
</tr>
<tr>
<td>Multi-h CPM</td>
<td>-</td>
<td>-</td>
<td>0.77 bit rates</td>
<td>12.0 dB</td>
</tr>
</tbody>
</table>
Conclusions

• SOQPSK and Multi-h CPM offer substantial reduction in bandwidth over PCM/FM, with little or no penalty in BER.
• SOQPSK-B is largely insensitive to IF filtering, while SOQPSK-A is more “delicate”
• SOQPSK-B offers better detection efficiency than SOQPSK-A, at the expense of slightly greater bandwidth
• Multi-h CPM offers almost 50% more bps / Hz than SOQPSK-A, and 2.5 dB better detection efficiency.
• Multi-h CPM nearly doubles the bps / Hz of SOQPSK-B, with the same detection efficiency.