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A modified OQPSK detection for MIL-STD SOQPSK in the satellite communication

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Abstract:

Military-standard (MIL-STD) shaped-offset quadrature phase-shift keying (SOQPSK) is a highly bandwidth-efficient constant-envelope modulation so that it has been applied in the satellite communication widely. We develope a simple detection of MIL-STD SOQPSK which is based on a modified OQPSK detection. The simple detection has the advantages of low complexity and good performance. And it's also suitable for other varieties of SOQPSK and FQPSK.

Key words: MIL-STD SOQPSK, Precoder, Modified OQPSK Detection, Detection Efficiency.

Introduction

In the recent years, many commercial companies have come up with ambitious commercial satellite launch plans[1][2]. The detection efficiency of satellite communication modulation has become increasingly important.

Dapper and Hill [3] described a form of continuous phase modulation (CPM) known as shaped BPSK (SBPSK) in the early 1980s. This modulation evolved into the constrained, ternary, full-response CPM using a rectangular frequency pulse that forms the basis for the MIL-STD 188-181 UHF Satcom standard. This modulation is also known as “Shaped Offset QPSK” (MIL-STD SOQPSK or SOQPSK-MIL) since it looks like an offset QPSK with smoothed phase transitions. An even more bandwidth efficient version of SOQPSK, called SOQPSK-TG, was adopted as an interoperable alternative to FQPSK in the IRIG 106 standard for aeronautical telemetry [4]. The family of SOQPSK waveforms, as described by Hill [3], are constant envelope signals with excellent spectral containment and detection efficiency. Furthermore, they can be detected using a standard OQPSK receiver. Performance results from Hill [5] indicate that a penalty of about 1 dB is incurred with MIL-STD SOQPSK, if a suboptimum OQPSK detector is used.

The objective of this paper is to investigate a modified OQPSK detection for MIL-STD SOQPSK to improve detection efficiency. The remainder of the paper includes a brief review of SOQPSK modulation characteristics, an introduction of percoder for SOQPSK, a comparison between the standard OQPSK detector and the modified OQPSK detector with simulation results, and the conclusion.

Characteristics of SOQPSK Modulation

The SOQPSK signal can be defined as a CPM signal[6]

$$s(t;\boldsymbol{\alpha}) = \exp\left\{ j\phi(t;\boldsymbol{\alpha})\right\} \tag{1}$$

where the phase is a pulse train of the form

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

and α_i is an *M*-ary symbol, T is the duration of each α_i, and h is the digital *modulation index*. The *phase pulse* $q(t)$ is usually thought of as the time-integral of a *frequency pulse* $g(t)$ with area 1/2 and duration *LT*.

$$q(t) = \int_0^t g(\tau)d\tau \tag{3}$$

$$\int_0^{LT} g(\tau)d\tau = q(LT) = 1/2 \tag{4}$$

For SOQPSK, α_i is drawn from a *ternary alphabet*, i.e. $\alpha_i \in \{-1,0,1\}$, where *M* =3. The *modulation index* is *h* = 1/2. The SOQPSK variants differ by their respective frequency pulses. Fig. 1 gives two typical examples: MIL-STD SOQPSK and SOQPSK-TG.

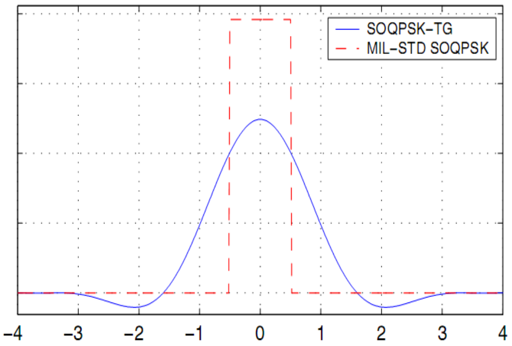

Fig. 1. The frequency pulses for SOQPSK-TG and MIL-STD SOQPSK.

As shown in Fig. 1, MIL-STD SOQPSK is full-response (*L* = 1) with a rectangular-shaped frequency pulse $g_{MIL}(t)$:

$$g_{MIL}(t) = \begin{cases} \frac{1}{2T}, & 0 \le t < T \\ 0, & others \end{cases} \qquad (5)$$

SOQPSK-TG is partial-response (L = 8) with a frequency impulse shaping filter function $g_{TG}(t)$:

$$g_{TG}(t) = n(t)w(t) \qquad (6)$$

Where[4]

$$n(t) = \left[\frac{A\cos\pi\theta_1(t)}{1-4\theta_1^2(t)}\right]\left[\frac{\sin\theta_2(t)}{\theta_2(t)}\right] \qquad (7)$$

$$\theta_1(t) = \frac{\rho Bt}{2T} \qquad (8)$$

$$\theta_2(t) = \frac{\pi Bt}{2T} \qquad (9)$$

$$w(t) = \begin{cases} 1, & \left|\frac{t}{2T}\right| \le T_1 \\ \frac{1}{2}\left[1+\cos\left(\frac{\pi\left(\left|\frac{t}{2T}\right|-T_1\right)}{T_2}\right)\right], & T_1 < \left|\frac{t}{2T}\right| \le T_1+T_2 \\ 0, & \left|\frac{t}{2T}\right| > T_1+T_2 \end{cases} \qquad (10)$$

The function $n(t)$ is a modified spectral raised cosine filter of amplitude A, rolloff factor ρ, and an additional time scaling factor B. The function $w(t)$ is a time domain windowing function that limits the duration of $g_{TG}(t)$. The amplitude scaling factor A is used to normalize the pulse shape such that the phase shift induced by a single frequency pulse is π/2 radians, as

$$\int_{-2(T_1+T_2)T}^{2(T_1+T_2)T} g(t)dt = \frac{\pi}{2} \qquad (11)$$

For SOQPSK-TG, other parameters are $\rho = 0.7, B = 1.25, T_1 = 1.5, T_2 = 0.5$.

Using Hill's article [5] for reference to a visual revelation, the top trace in Fig. 2 shows that, for unshaped OQPSK, the frequency pulse is simply a delta function, $g(t) = (1/2)\delta(t)$. In each bit period, the frequency pulse is either present or absent. If present, the phase will shift by π/2 radians, but it can only go in the "allowed" direction for that bit period. Because of the offset between the I and Q channels, the allowed direction will depend on the current state, such that the signal will change in I value, or Q value, but never both at the same time.

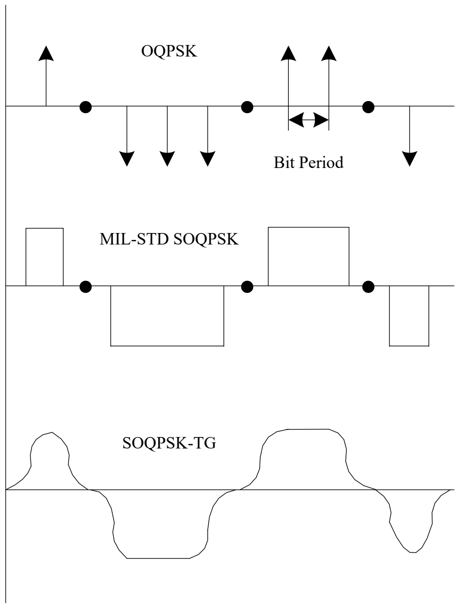

Fig. 2. Frequency pulses for Offset QPSK variants.

MIL-STD SOQPSK is depicted by the middle trace in Fig. 2. Again, the area of the frequency pulse is exactly π/2 radians, but the shape is rectangular, with a duration of one bit period. This has the effect of shifting the phase of the carrier by exactly one-quarter rotation over a span of one bit. At any instant in time, the phase is either stationary, or is moving at a constant rate of one-quarter of the bit rate.

The bottom trace in Fig. 2 represents the frequency pulse of SOQPSK-TG, which will also shift the phase of the signal by π/2 radians in one bit period. It is important to note that all of these waveforms are perfectly constant envelope; only the phase trajectory differs from one variant to the next. It is also significant that all of them can be demodulated with a conventional OQPSK detection.

Fig. 3 shows the power spectral density of MIL-STD SOQPSK and SOQPSK-TG. The primary difference between them is that SOQPSK-TG improves its sidelobes more effectively, which is achieved by partial-response characteristic at the expense of higher complexity. To emphasize the highly bandwidth efficiency of SOQPSK, unfiltered BPSK and OQPSK are also shown for reference.

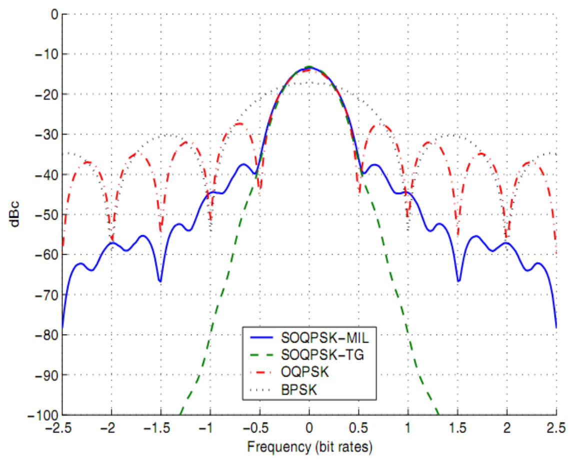

Fig. 3. Power spectral density of MIL-STD SOQPSK and SOQPSK-TG.

In this paper we concentrate on MIL-STD SOQPSK.

Precoder for SOQPSK

The characteristic that sets SOQPSK apart from ordinary CPM is that the ternary data is the output of a precoder, as shown in Fig. 4.

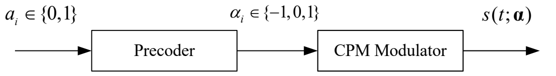

Fig. 4. Signal model for SOQPSK.

The precoder converts the binary data $a_i \in \{0,1\}$ into ternary data $\alpha_i \in \{-1,0,1\}$ according to the mapping [7]

$$\alpha_i = (-1)^{i+1} d_{i-1}\left(\frac{d_i - d_{i-2}}{2}\right) = (-1)^{i+1}(2a_{i-1}-1)(a_i - a_{i-2}) \tag{12}$$

Where $d_i = 2a_i - 1 \in \{+1,-1\}$ and $a_i \in \{0,1\}$.

Therefore, SOQPSK is viewed as a *constrained* ternary CPM. The mapping in Equation (12) imposes three important constraints on the ternary data [8]

1) While α_i is viewed as being *ternary*, in any given symbol interval α_i is actually drawn from one of two *binary* alphabets: {0, 1} or {0, −1}.

2) When $\alpha_i = 0$, the binary alphabet for α_{i+1} switches from the one used for α_i, when $\alpha_i \neq 0$, the binary alphabet for α_{i+1} does not change.

3) A value of $\alpha_i = 1$ can not be followed by $\alpha_{i+1} = -1$, and vice versa.

The original motivation for SOQPSK is that Equation (12) leads to a simple symbol-by-symbol detection architecture [5]. Conceptually speaking, we can separate the input bits for even symbol times and odd symbol times into *inphase* and *quadrature* bit streams, as in

$$a_{I,n} = a_{2n}, \qquad a_{Q,n} = a_{2n+1} \tag{13}$$

The role of the precoder is to ensure that the phase state of the CPM modulator is oriented correctly so that the *inphase* and *quadrature* bits can be recovered using a standard OQPSK detector.

A Modified OQPSK Detector for MIL-STD SOQPSK

As mentioned above, MIL-STD SOQPSK can be demodulated using a standard OQPSK detector [3][5], as shown in Fig. 5. The detector is simple and easy for hardware implementation, whereas with a detection penalty of about 1 dB.

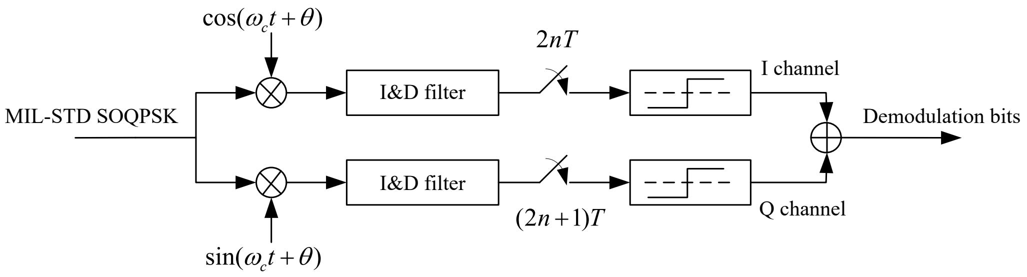

Fig. 5. Block diagram of a standard OQPSK detector.

To improve the detection efficiency, a modified OQPSK detector for MIL-STD SOQPSK is investigated, as shown in Fig. 6. The only difference between two detectors is the detection filter before data judgement. For standard OQPSK detector, the detection filter is just an integrate and dump (I&D) filter. For modified OQPSK detector, the detection filter is a modified filter, which can match MIL-STD SOQPSK better, so as to improve the bit error rate performance with only little increased complexity. The wave shape of the modified filter is shown in Fig. 7.

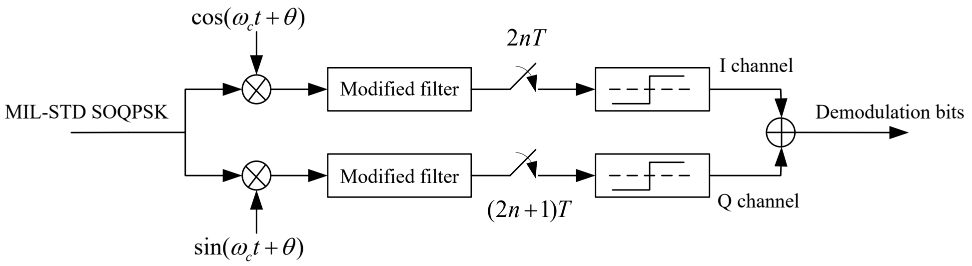

Fig. 6. Block diagram of a modified OQPSK detector.

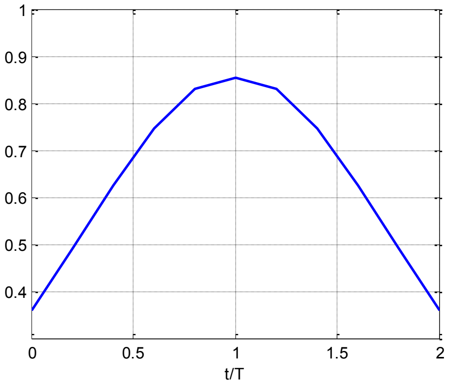

Fig. 7. Wave shape of the modified filter.

Simulation Results

The performances of MIL-STD SOQPSK with both detectors are simulated by MATLAB Software. The results are shown in Fig. 8, along with the theoretical curves of OQPSK and MIL-STD SOQPSK. A simple comparison between two detectors is also given in Tab. 1.

Tab. 1: Comparison of two detectors

Modulation Type	Eb/No (dB) required for BER = 10^{-5}		
	Standard OQPSK Detector	Modified OQPSK Detector	Theoretical Optimum Detector
MIL-STD SOQPSK	11.01	10.54	9.90

Compared to the standard OQPSK detector with I&D filter, the modified detector with a better matched filter has an improvement of 0.47 dB at BER = 10^{-5} for MIL-STD SOQPSK, although is still worse than the theoretical optimum detector about 0.64 dB. From Fig. 8, we also see that at BER = 10^{-5}, MIL-STD SOQPSK is about 0.3 dB worse than OQPSK, both in theory. But MIL-STD SOQPSK has the higher bandwidth efficiency than OQPSK, as shown in Fig. 3.

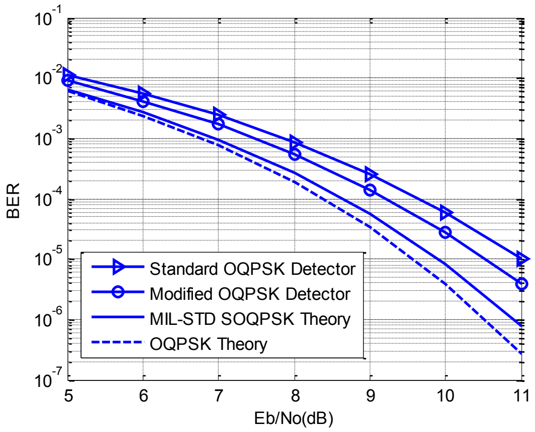

Fig. 8. Performances of MIL-STD SOQPSK with both detectors.

Conclusion

We have investigated a modified OQPSK detector for MIL-STD SOQPSK to improve detection efficiency. Compared to the standard OQPSK detector with I&D filter, the new modified OQPSK detector with a better matched filter has an improvement of 0.47 dB at BER = 10^{-5} for MIL-STD SOQPSK , with only little increased complexity. And this modified OQPSK detector is also suitable for other varieties of SOQPSK and FQPSK[9].

M. J. Dapper and T. J. Hill, SBPSK: A robust bandwidth-efficient modulation for hard-limited channels, Proceedings of IEEE MILCOM, October 1984; doi:10.1109/MILCOM.1984.4794893

References

[1] Zhang Xianhui and Shen Guosong, Application of SQPSK Modulation in TDRSS, *Journal of Telemetry, Tracking and Command*,2007,28(z1):26-29; doi:10.3969/j.issn.2095-1000.2007.z1.005.

[2] Yan Jianhua, Li Xiaomei and Zhang Tao, Research on ETSI TCR standards and TT&C system of commercial satellite, *Journal of Telemetry, Tracking and Command*, 2020,6(41).

[3] M. J. Dapper and T. J. Hill, SBPSK: A robust bandwidth-efficient modulation for hard-limited channels, Proceedings of IEEE MILCOM, October 1984; doi:10.1109/MILCOM.1984.4794893.

[4] Range Commanders Council Telemetry Group, Range Commanders Council, White Sands Missile Range, New Mexico. IRIG Standard 106-23: Telemetry Standards, 2023. [Online]. Available: http://jcs.mil/RCC/manuals/106-23.

[5] T. Hill, An Enhanced, Constant Envelope, Interoperable Shaped Offset QPSK (SOQPSK) Waveform for Improved Spectral Efficiency, *Proceedings of the International Telemetering Conference*, San Diego, CA, October 2000.

[6] J. B. Anderson, T. Aulin, C-E. Sundberg. Digital Phase Modulation, *Plenum Press*, New York, 1986.

[7] M. K. Simon, Bandwidth-Effcient Digital Modulation with Application to Deep-Space Communication, *New York: John Wiley & Sons, Inc.*, January 2003. Also published as part of the JPL Deep Space Communications and Navigation (DESCANSO) Monograph Series, JPL Publication 00-17, Jet Propulsion Laboratory, Pasadena, California, June 2001.

[8] M. Simon and L. Li. A cross-correlated trellis-coded quadrature modulation representation of MIL-STD shaped offset quadrature phase-shift keying. *IPN (Interplan. Network) Progress Report* 42-154, August 2003.

[9] Ding Xingwen, Song Jianyong, Chen Ming and Lu Manhong, A modified OQPSK detection for SOQPSK-TG in aeronautical telemetry. *Proceedings of the International Telemetering Conference*, San Diego, CA, October 2014.