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Performance Analysis of Different Phase Shift Keying Modulation Schemes in Aeronautical Channels*

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Abstract: This paper undertakes the performance evaluation and comparison of different phase shift keying (PSK) modulation schemes in aeronautical channels. Specifically, bit error rate (BER) curves and outage probabilities of various modulation schemes in high dynamic environments are investigated by means of numerical analysis and computer simulation. Simulation results show that the performance of all modulation schemes degrades with the increase of the power ratio or dynamic factor, and that differential quadrature phase shift keying (DQPSK), differential 8 phase shift keying (D8PSK), 16 and 64 differential amplitude and phase shift keying (DAPSK) perform better than other same order modulation schemes, respectively. As the conclusion, the differential modulation schemes are more suitable for the aeronautical channels in order to withstand the Doppler shift and the changing rate of the Doppler.

Key words: *M*-PSK; *M*-DPSK; *M*-DAPSK; aeronautical channels; Doppler effect

Introduction

With the rapid development of the air transport industry, the aeronautical communications has become the key enabler for achieving a high efficient and safe air transport system that is capable of meeting future demands. In order to fulfill the requirements of the high spectrum efficiency and system capacity in the aeronautical communications, appropriate modulation schemes should be adopted, e.g., differential quadrature phase shift keying (DQPSK) used in military Link-11 and differential 8 phase shift keying (D8PSK) used in VHF data link (VDL) mode 2. Compared with the traditional terrestrial mobile radio channels, aeronautical channels not only suffer the multipath fading resulting from the reflection, scattering, diffraction, and shadowing effects together with a direct line-of-sight (LOS) path[1], but also possess their own characteristics, such as the large Doppler shift and the great changing rate of the Doppler as a result of the ultra high varying velocity of the aircraft. Due to the difficulties as well as the cost and complexity associated with carrier phase recovery, differential modulation schemes, which do not require a coherent phase reference at the receiver, are generally preferred to coherent modulation for aeronautical applications. However, so far, the systematic bit error rate (BER) performance evaluation in aeronautical channels has not been reported. Therefore, it is significant to analyze and compare the different performances among the different phase shift keying (PSK) modulation schemes in aeronautical channels.

1 *M*-PSK/*M*-DPSK/*M*-DAPSK Modulation Schemes

For *M*-PSK, all of the information is encoded in the phase of the transmitted signal. Thus, the transmitted

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signal over one symbol time is given by Ref. [2].

$$s_i(t) = \Re\{Ag(t)\mathrm{e}^{\mathrm{j}2\pi(i-1)/M}\mathrm{e}^{\mathrm{j}2\pi f_c t}\},\ 0 \leqslant t \leqslant T_s \qquad (1)$$

where A is a typical function of the signal energy, $g(t)$ is shaping pulse, f_c is the carrier frequency, T_s is the symbol period, and $\theta_i = 2\pi(i-1)/M,\ i=1,2,\ldots,M=2^K$ are the different phases in the signal constellation points that convey the information bits. As for M-PSK, constellation mapping is usually done by gray encoding, where the messages associated with signal phases that are adjacent to each other differ by one bit value[2]. Figure 1 illustrates the constellations of QPSK and 8PSK with gray encoding.

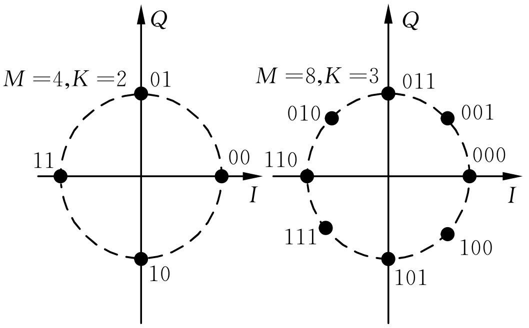

Fig. 1 QPSK and 8PSK constellations with gray encoding

Differential modulation M-DPSK falls in the more general class of modulation with memory, where the symbol transmitted over time $[kT_s, (k+1)T_s]$ depends on the bits associated with the current message to be transmitted and the bits transmitted over prior symbol times. The basic principle of differential modulation is to use the previous symbol as a phase reference for the current symbol, for avoiding the need for a coherent phase reference at the receiver. Specifically, the information bits are encoded as the differential phase between the current symbol and the previous symbol. The phase transitions for DQPSK modulation are summarized in Table 1.

The M-DAPSK modulation scheme has been extended to a combined differential amplitude and phase modulation in order to achieve a higher spectrum efficiency and better performance[3]. For 64DAPSK, whose constellation is illustrated in Fig. 2, every symbol consists of six bits, b_1, b_2, b_3, b_4, b_5, b_6, which can be divided into two different groups (b_1, b_2, b_3, b_4) and (b_5, b_6) for phase and amplitude differential modulation respectively. This phase differential modulation process is the same as the 16DPSK. The amplitude states $|S_i|$ are chosen from the constellation diagram depending on the previous amplitude state $|S_{i-1}|$ and the two input information bits (b_5, b_6). The detailed coding rule of the amplitude is presented in Table 2[4-9].

Table 1 Mapping for DQPSK with gray encoding

Bit sequence	Phase transition
00	0
01	π/2
11	π
10	−π/2

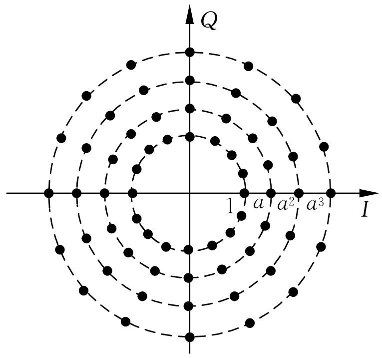

Fig. 2 64DAPSK constellation

Table 2 64DAPSK amplitude differential modulation

$\lvert S_{i-1}\rvert$	$\lvert S_i\rvert$				
	(b_5, b_6)=	00	01	11	10
1		1	a	a^2	a^3
a		a	a^2	a^3	1
a^2		a^2	a^3	1	a
a^3		a^3	1	a	a^2

2 System Structure and Aeronautical Channels

The system structure with different phase shift keying modulation schemes is shown in Fig. 3. Referring to this figure, input bits from channel encoder are passed through the differential encoder for the differential non-coherent modulation schemes. Since the differential encoder is not employed for the coherent modulation schemes, e.g., M-PSK, the block is depicted in dashed line. The resultant symbols are mapped to the relevant constellation and sent to the aeronautical channel. On the contrary, at the receiver side, the received signals from the aeronautical channel are sent to the carrier recovery block followed by phase recovery block. Also, these two blocks are depicted in dashed line as they are only considered for the coherent modulation schemes. Then, the output symbols are