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SOQPSK – A Spectrally Efficient Modulation Scheme for Aeronautical Telemetry Applications

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Abstract*—* ***The demand for communication services is increasing each passing day and so is the demand for the limited RF spectrum. As the spectrum is being vied by the commercial users, the necessity arises to make use of the available spectrum more judiciously. Bandwidth restrictions have led the designers' world over to graduate from analog telemetry schemes to advanced digital schemes. In this paper we bring out the need for changing over to digital scheme, study continuous phase modulation (CPM) and analyze Shaped Offset Quadrature Phase Shift Keying (SOQPSK-TG), recommended by Inter Range Instrumentation Group (IRIG) for aeronautical telemetry and compare it with the proven traditional analog PCM/FM for airborne data links working at 4 Mbps rate.***

Index Terms**—CPM, Pulse Code Modulation, SOQPSK-TG, Power Spectral Density, Bit Error Rate.**

I. INTRODUCTION

Telemetry schemes currently functioning in most fighter aircrafts are analog (PCM/FM) schemes comprising of inputs from analog video and audio channels, data from analog vibration sensors, and digital PCM parameters from various other inputs as shown in Fig 1.

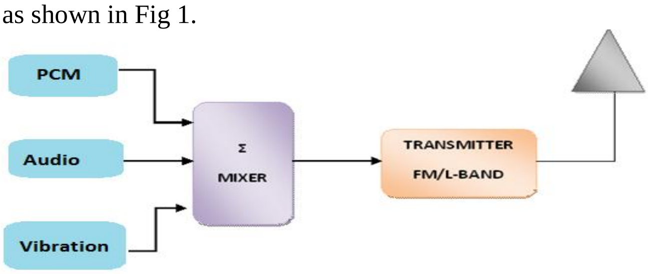

Fig. 1: PCM/FM Modulation Scheme

The requirement for changing over to digital scheme arises with the need to transmit more information in the available bandwidth with lower bit error rate. Further as we are moving into a digital era, the digital modulation schemes has the added advantage of compatibility with digital data services. With the prospects of implementing error detection and correction, digital schemes result in better quality data in a more secure and bandwidth efficient way. The choice of modulation scheme significantly affects the characteristics, performance and resulting physical realization of a communication system. The modulation scheme needs to be chosen giving, consideration to the required data rate, acceptable level of latency, available bandwidth, anticipated link budget and target hardware cost, size and power consumption [3]. Digital modulation schemes can be broadly classified as phase shift keying (PSK) methods and frequency shift keying (FSK) methods. For aeronautical telemetry applications, the modulation schemes should have less power in side lobes so that cross channel interference is reduced. Multiple numbers of transmissions should be possible in the available bandwidth. That is the scheme should be bandwidth efficient. In addition, modulation schemes that introduce phase discontinuities will tend to introduce undesirable frequency side lobes when amplified through a non–linear amplifier. However, linear amplifiers are less power efficient (transmitted power versus power supplied) than non–linear amplifiers. In conventional FSK or PSK the phase of the carrier may change at the beginning of each symbol. Hence the requirement arises to go for modulation schemes in which the phase of the signal changes smoothly from one symbol to another symbol as a function of frequency pulse. This class of modulation schemes is classified as continuous phase modulation (CPM).

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II. CONTINUOUS PHASE MODULATION

By imposing, within a modulation scheme, that the phase of a carrier be continuous from one symbol to the next, the level of sidebands of the transmitted signal can be reduced. CPM schemes ensure constant envelope modulation that reduces spectral re-growth and avoids signal distortion due to nonlinearity in high power amplifiers. The strength of the side lobe levels of the spectrum are further reduced by passing the modulating NRZ data through pre-modulation pulse shaping filters. Base band pulse shaping smoothens the phase trajectory of signal, and hence stabilizes the instantaneous frequency over time. The phase of CPM signal is [1]

$$\phi(t,\alpha) = 2\pi h \int_{-\infty}^{\infty} \sum_{i=-\infty}^{+\infty} \alpha_i \, g(t - iT_s)dt \qquad (1)$$

Here, g(t) is the frequency pulse, h is the modulation index. The phase of the signal is continuously varied with respect to g(t). The coefficient α_i stands for the current pre-coded data bit depending on the modulation scheme of CPM. Continuous phase is effectively achieved with CPFSK (continuous phase frequency shift keying) schemes like minimum shift keying (MSK). Recently shaped offset quadrature phase shift keying (SOQPSK) is introduced as a bandwidth efficient modulation technique where data precoding and frequency pulse design takes care for channels with higher premium on bandwidth. In this paper, Analytical modeling is carried out for IRIG recommended Shaped Offset Quadrature Phase Shift Keying (SOQPSK) [4] and its performance evaluated and compared with PCM/FM.

III. ANALYTICAL MODELLING OF SOQPSK MODULATION

The SOQPSK modulation scheme with pre-coder is shown in Fig. 2.

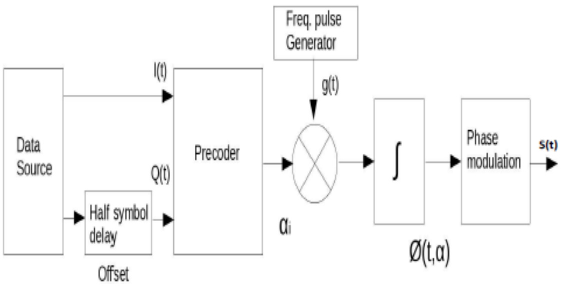

Fig. 2.:Block diagram of SOQPSK modulator

However, in SOQPSK the message bit stream is divided into in-phase (I) and quadrature phase (Q) channels, and one of them is delayed by half symbol time (*Ts/*2) duration as it happens for OQPSK. It is also called as ternary CPM, as it generates $\alpha_i \in \{-1,0,1\}$from d_i using the precoding algorithm expressed as

$$\alpha_i = \frac{(-1)^{i+1} d_{i-1}(d_i - d_{i-2})}{2} \qquad (2)$$

This ternary data α_i determines the phase transitions $\{-\frac{\pi}{2}, 0, +\frac{\pi}{2}\}$ corresponding to $\alpha_i$equals to{-1,0,+1} such that α_i never assumes values {1,-1}consecutively or vice versa. The 8 state transitions of precoder data for SOQPSK modulation is shown in the Trellis diagram of Fig. 5. Two states are considered in the diagram, current state and the next state, depending on the value of α_i. There are three bits in each state, MSB represents the input whether it is I or Q, I is represented with 1 and Q is represented with 0. The next bit and LSB together represents the present IQ data at the precoder input. This IQ symbol can take four possible values among {00, 10, 11, 10}, and are mapped to corresponding phase states, e.g. $\{\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}\}$. Hence, each IQ corresponds to one phase state. For example, consider the first state in Fig. 3 to be 000. In this case, the MSB represents the Q channel data that is present at precoder input having value either 1 or 0, with the present IQ as 00 specified by next bit and LSB together. Only one bit changes at a time as at the precoder input it is OQPSK. So here Q channel data would change while transiting to the next state with MSB. Hence, the next state would be either 100 or 101. As there are two possible next states 100 and 101, and for example the next state is 101, the corresponding MSB is 1. Therefore, the terminating phase state is $\frac{7\pi}{4}$. Hence, the phase change occurred is $\frac{\pi}{2}$. Assuming binary to antipodal, the mapping 0 to 1, 1 to 1 such that the present IQ symbol representing d_{i-1} and d_{i-2} have transition to -1 and 1 respectively. In this case the value of *i* is odd as we have considered the case for the Q channel. After substituting the values of data bits in (2) the value of α_i is -1, marked on the corresponding Trellis path.

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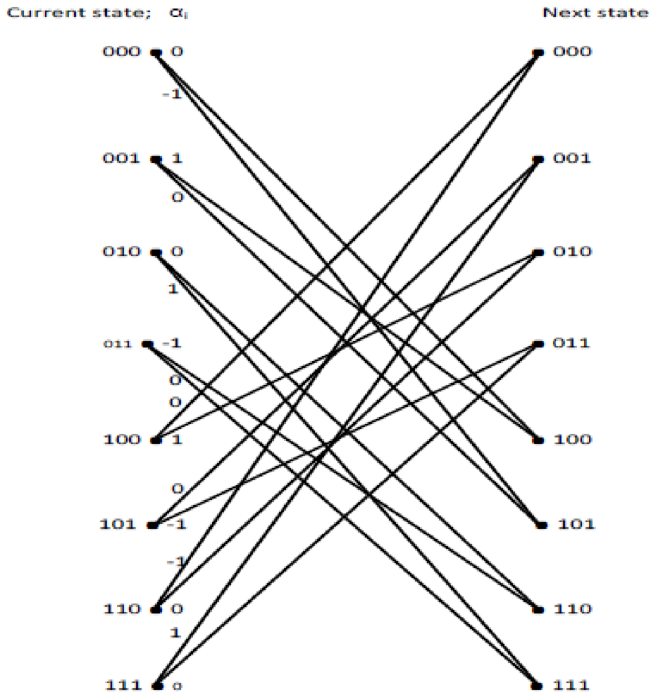

Fig. 3: State Trellis diagram for SOQPSK.

There are several varieties of SOQPSK scheme above of which SOQPSK-TG is more popular version as it achieves superior spectral containment of energy compared to other versions of SOQPSK-TG frequency pulses is denoted by $g_{TG}(t)$, and is expressed as [2]

$$g_{TG}(t) = n(t)w(t) \quad (3)$$

The raised cosine impulse response $n(t)$ is defined as [2]

$$n(t) = \frac{A\cos(\pi\rho Bt/T_s)}{1-4(\rho Bt/T_s)^2}\frac{\sin(\pi Bt/T_s)}{(\pi Bt/T_s)} \quad (4)$$

and window function $w(t)$ is [2]

$$w(t) = \begin{cases} 1 & \left|\frac{t}{T_s}\right| < T_1 \\ \frac{1}{2} + \frac{1}{2}\cos\pi\frac{(\frac{t}{T_s} - T_1)}{T_2} & T_1 \le \left|\frac{t}{T_s}\right| < T_1 + T_2 \\ 0 & \left|\frac{t}{T_s}\right| < T_1 + T_2 \end{cases} \quad (5)$$

The frequency and phase pulse for SOQPSK-TG are as shown in Fig 4.

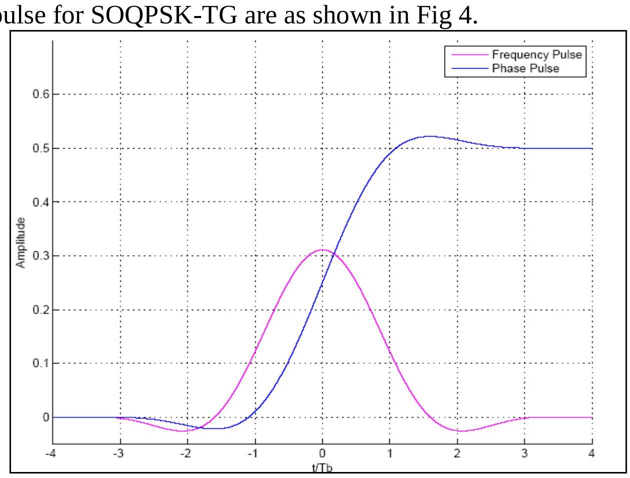

Fig. 4: SOQPSK-TG Frequency pulse and Phase pulse

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IV. PRACTICAL EVALUATION AND RESULTS

The simulations of spectrum plots of SOQPSK-TG with respect to PCM-FM are shown in Fig. 5. We have utilized 4Mbps data rate that is a comparable number for video, audio and other data streams required for digital telemetry [5]. It is seen from the spectrum plots that SOQPSK-TG better bandwidth efficiency compared to PCM/ FM. The simulated 99% bandwidth of PCM/FM in Fig. 5 is around 4.64 MHz that is 1.16*Rb*, where *Rb* is the data rate.

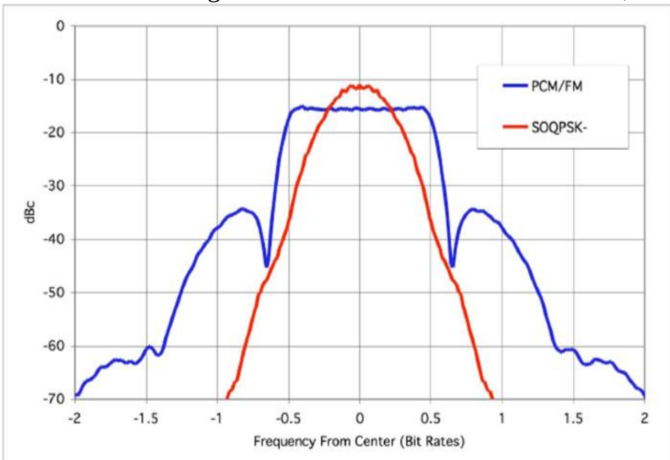

Fig. 5: Simulated Spectral Comparison.

Transmission was carried out at S-band frequency of 2.3 GHz for a data rate of 4 Mbps for PCM/FM and SOQPSK-TG [6]. The power spectral density plots captured in spectrum analyzer is brought out in Fig. 6 and Fig.7. The 99% bandwidth obtained is 4.26 MHz as shown in Fig. 6. Similarly for SOQPSK-TG implementation, the 99% BW is around 3.12 MHz in Fig. 5 that is 0.78*Rb* where as the practically occupied bandwidth in Fig.7 is 3.11 MHz. Thus it is evident that the practical evaluation results are comparable with the simulation results. Bit Error Rate values were estimated for different values of Eb/No by attenuating the input SOQPSK RF power level to the SOQPSK demodulator and comparing the input signal and demodulator output in BER tester. The plot of BER Vs Eb/No for SOQPSK-TG is shown in Fig.8.

V. CONCLUSION

The summary of the simulation and practical implementation of the two modulation schemes are as follows: PCM/FM is easy to acquire, is robust and has the best theoretical BER but the bandwidth efficiency is the least. PCM/FM is best suited for data rates less than 2 Mbps.

Fig. 6: Practical PCM/FM spectrum at 4 Mbps in S-band.

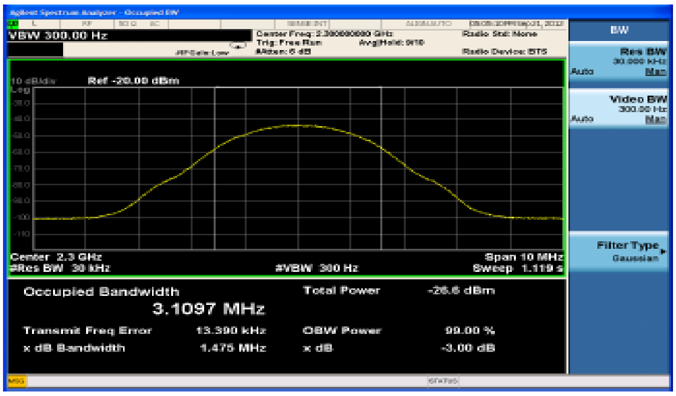

Fig. 7: Practical SOQPSK Spectrum at 4Mbps in S-band.

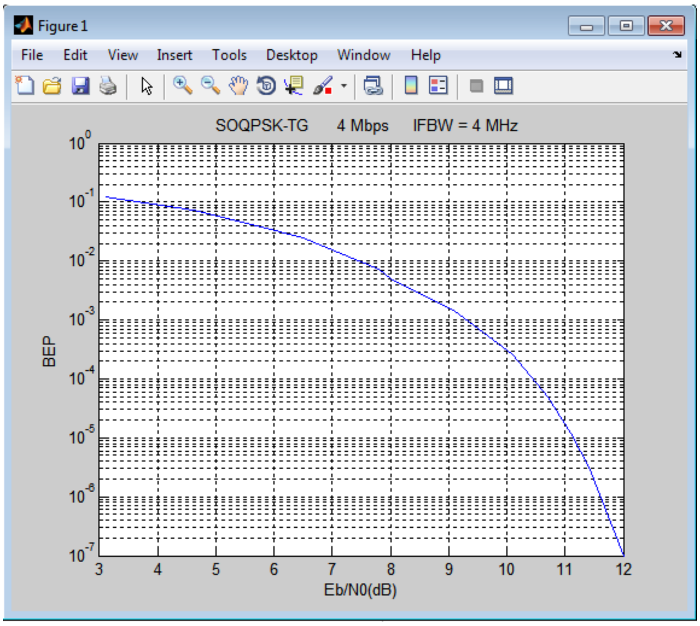

Fig. 8: BER Vs Eb/No plot for SOQPSK-TG

SOQPSK has the demerit of more number of bits to lock but with the advancement in the receiver algorithms the acquisition time is becoming lesser. Moreover, SOQPSK-TG is recommended by IRIG telemetry standards and supported by the telemetry equipment manufacturers.

Table. 1: Comparison of PCM/FM and SOQPSK-TG

CHARACTERISTICS	PCM/FM	SOQPSK
BANDWIDTH EFFICENCY BITS/S/Hz	0.7	0.8
99%B.W	1.16Rb	0.78*Rb
Eb/No 10exp-5	12	12

Thus it is concluded that SOQPSK-TG scheme is a good choice for digital telemetry purposes. In these results SOQPSK-TG has high spectral efficiency, good theoretical BER and is optimum for data rates greater than 4 Mbps. For arriving at this conclusion, we have shown the detailed analysis of SOQPSK-TG and practically evaluated the scheme and compared the results with PCM/FM.

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