FQPSK-L: An Improved Constant Envelope Modulation Scheme for QPSK

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ABSTRACT

A new constant envelope modulation scheme and architecture for QPSK by cubic spline interpolation methods which increase spectral efficiency and power efficiency, named FQPSK-L, is presented. This modulation technique is an extension of the Feher Quadrature Shift Keying (FQPSK) patented technologies, see Ref [1]. Being a constant envelope modulation, FQPSK-L can operate with class C power amplifier without spectrum regrowth. We achieve a more compact spectrum with comparable bit error rate performance. For example, FQPSK-L is about 20% more spectral efficient than GMSK BT_b=0.3 from 40 to 70 dB attenuation point. Moreover, FQPSK-L intrinsically has spikes at $f_c \pm 0.5f_b$, $f_c \pm 1.0f_b$, $f_c \pm 1.5f_b$, ... which are useful for carrier recovery, symbol time recovery and fading compensation. In Rayleigh fading channel, FQPSK-L outperform GMSK BTb=0.3 by 0.8 dB. FQPSK-L is an excellent scheme for wireless and satellite communications which require high spectral and power efficiency.

KEY WORDS

Modulation, Feher's quadrature phase shift keying, QPSK, non-linear amplification, bandwidth efficiency.

1. Introduction

Constant envelope modulation techniques such as MSK, GMSK, and digital FM can be nonlinearly amplified without spectral regeneration. This is particularly important for portable phones where battery power supply is limited. Modulation techniques can improve the efficiency of wireless system significantly, with impact on cost, size, power and spectral efficiency, data transmission, throughput speed, and capacity. The proper combination of modulation and RF amplification technologies can improve the power and spectral efficiency of communication systems.

QPSK has been widely used as digital modulation scheme. For example, IEEE802.11 Wireless Local Area Network (WLAN) Direct Sequence Spread Spectrum (DSSS) adopts DQPSK as one of its modulation scheme.

An architecture and algorithm for constant envelope modulation scheme with good spectral and power efficiency, named FQPSK-L, is presented. Being a constant envelope modulation, FQPSK-L can operate with class C power amplifier without spectrum regrowth. A compact spectrum is achieved by applying the cubic spline interpolation method to QPSK type signals. Due to its non-offset scheme, a significant advantage of FQPSK-L is that the non-coherent differential (or discriminator) demodulation scheme is possible in addition to coherent demodulation.

In section 2, the transmitter architecture is described. The block diagram and phase mapping algorithm are discussed. The spectral properties of FQPSK-L is obtained by simulation.

In section 3, we compare the BER performance of FQPSK-L and GMSK BT_b=0.3. In Rayleigh fading, FQPSK-L outperforms GMSK BT_b=0.3 by 0.8 dB.

We conclude in section 4 that the spectrally and power efficient FQPSK-L is an excellent scheme for wireless and satellite communications.

2. Transmitter

2.1 Simulation model

The block diagram of FQPSK-L modulation architecture is shown in Fig. 1. The input binary data with bit duration T_b are two-to-four level converted and mapped into phase angle. There are only four possible phases, ±45°, ±135°, for FQPSK-L. The phase shift for FQPSK-L are one of 0°, ±90°, ± 180°. To get a narrower spectrum, we have to reduce the possible phase change. So, the sign of the 180° phase change depends on its previous sign of phase shift. If the previous phase shift is -90°, then the current 180° phase shift should be -180° instead of +180°. Once the unwrapped phases are gotten, we can apply the interpolation methods to get smooth phase transition waveforms. The smoothed phase θ_{ki} are sent into the cosine and sine functions, respectively, where θ_{ki} stands for the *i*-th sample of the *k*-th symbol. These give the In-phase/Quadrature (I/Q) baseband signals which are used to modulate the carrier. After summing the I and Q signals, we have constant envelope signals which can be non-linearly amplified without spectral regeneration.

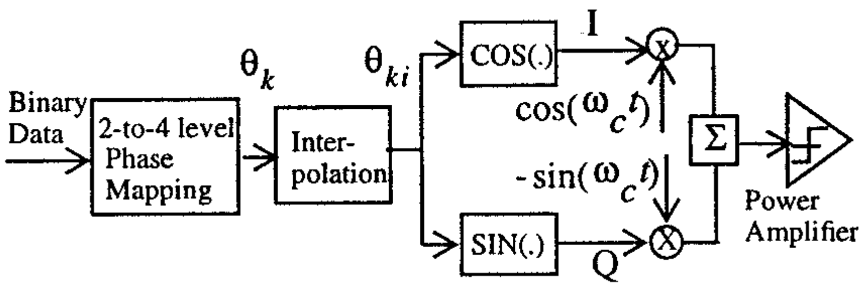


Fig.1 Block diagram of the transmitter of FQPSK-L system.

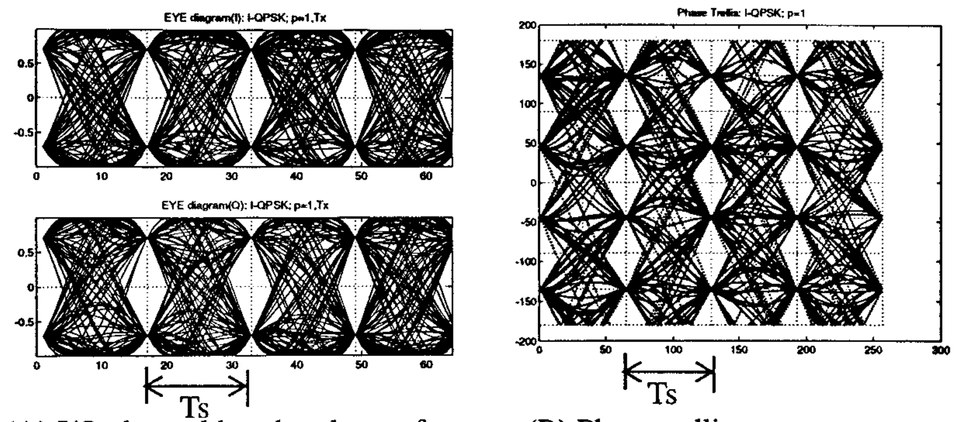
We use cubic spline interpolation method [3] in this paper. Other interpolation methods such as linear interpolation, cubic interpolation, cubic smoothing spline, and spline with tension [4] have been considered in [5].

In an actual transmitter, I_{ki}/Q_{ki} are D-to-A converted to analog signal and then followed by Low-Pass Filter (LPF) to remove higher frequency components. The analog I/Q baseband signals are modulated with the carrier and amplified by a power amplifier. Because of being constant envelope, FQPSK-L can be operated with fully non-linear (saturated, C-class or hard-limited) power amplifier without spectral regrowth. For cubic spline interpolation, the phase curves are third order polynomials in each symbol duration. By taking the derivatives of these polynomials, one can implement the equivalent FM system using VCO (Voltage-Controlled-Oscillator).

In the simulation, we use baseband equivalent model. The I/Q baseband signals are passed through the channel model. The receiver BPF is replaced by its equivalent LPF. The natural cubic spline method is used in this paper.

The I/Q channel eye diagram and phase trellis of FQPSK-L are plotted in Fig.2. The power spectrum density (PSD) of FQPSK-L and GMSK BTb=0.3 generated by simulation are shown in Fig.3. Note thatFQPSK-L has spikes at $f_c \pm 0.5f_b$, $f_c \pm 1.0f_b$, $f_c \pm 1.5f_b$, ... which are useful for carrier recovery, symbol time recovery and fading compensation. The significant spectral property is that FQPSK-L is 20% to 25% more efficient than that of GMSK BT_b=0.3 from 40 to 70 dB attenuation range. To verify the spikes in the spectrum of FQPSK-L, we can change the length of the input data, which is a Pseudo Random Binary Sequence (PRBS) in the simulation. The longer the sequence in time domain, the finer the resolution in the frequency domain. For example, by doubling the input length of the PRBS, the spikes in frequency domain increase by 3 dB over the continuous components. We use 2048 as the input data length in Fig.3.

The ratio of the out-of-band power to the total power are plotted in Fig.4. Based on the definition of the 99% in-band-power, FQPSK-L with the cubic spline interpolation has the spectral efficiency of 1.2 b/s/Hz, while GMSK BT_b=0.3 has the spectral efficiency of 1.1 b/s/Hz. The FQPSK-1 [2] is also plotted in Fig.4 for comparison.



(A) I/Q channel baseband waveform (B) Phase trellis

Fig.2 I/Q channel baseband waveforms and phase trellis of FQPSK-L

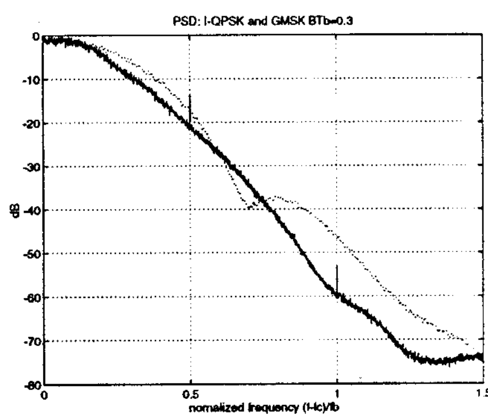


Fig.3 Power Spectrum Density of FQPSK-L (solid) and GMSK BTb=0.3 (dotted)

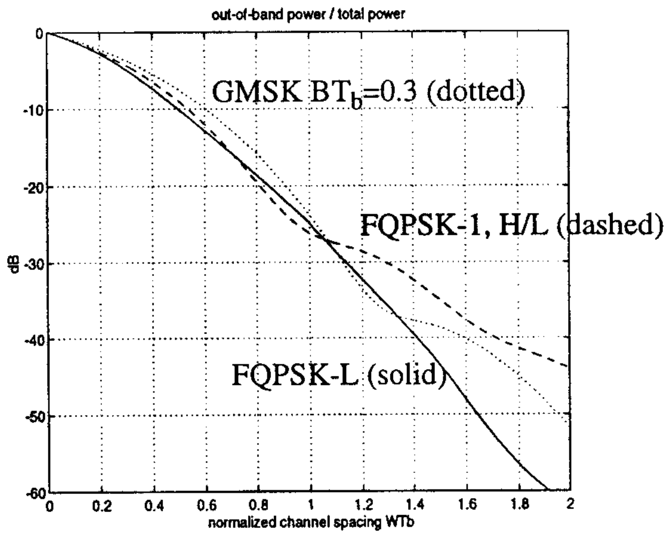


Fig.4 Out-of-Band Power vs. Normalized Channel Spacing plot for FQPSK-L, FQPSK- I with hardlimiter and GMSK BT_b=0.3.

3. BER performance

The BER performance of coherent demodulation of FQPSK-L, FQPSK-1 [2] and GMSK BTb=0.3 in AWGN channel are obtained by computer simulations and the results are compared in Fig.5. The horizontal axis is E_b/N_o in dB scale, where E_b is the bit energy and N_o is the normalized noise power (power in 1 Hz bandwidth width). The vertical axis is the bit error rate. Butterworth 4th order receiver BPF with B_iT_b=0.6 is employed for FQPSK-L and Gaussian BPF with B_iT_b=0.6 is employed for GMSK BT_b=0.3. The eye diagram for FQPSK-L in receiver is shown in Fig.6. The bit rate used in this experiment is 7.27k b/s. The receiver BPF is Butterworth 4th order with 2.2 k Hz bandwidth which corresponds to a normalized bandwidth with B_iT_b=0.6. Note that the eye openings are asymmetrical due to the non-constant group delay of the receiver BPF.

The BER performance for coherent detection of FQPSK-L in slow Rayleigh fading channel is depicted in Fig.7. Here, we assume perfect Carrier Recovery (CR) and Symbol Time Recovery (STR). To obtain this result, we use the same set of receiver BPF as in the AWGN case. The normalized Doppler frequency is f_DT_b= 1.65 x 10^{-3} that corresponds to a 40 Hz Doppler and a data rate 24.3K b/s. The Butterworth 4th order receiver BPF with BiTb=0.6 is employed for FQPSK-L. Ideal Gaussian BPF with BiTb=0.6 is employed for GMSK BTb=0.3. Comparing with coherent detection of GMSK with BT_b=0.3, FQPSK-L is 0.8 dB better under the same BER requirements.

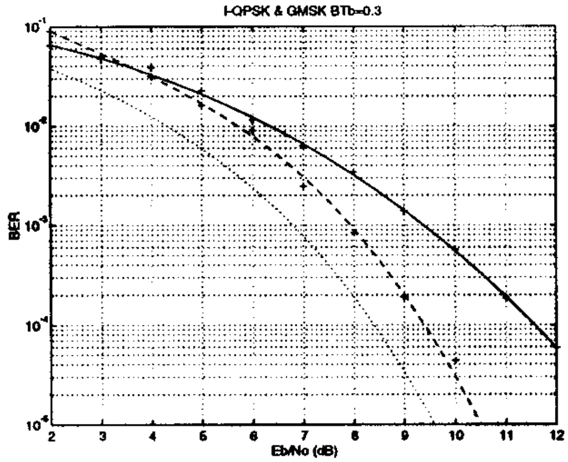


Fig.5 BER performance of coherent FQPSK-L (solid), GMSK BTb=0.3 (dashed), and ideal QPSK dotted .

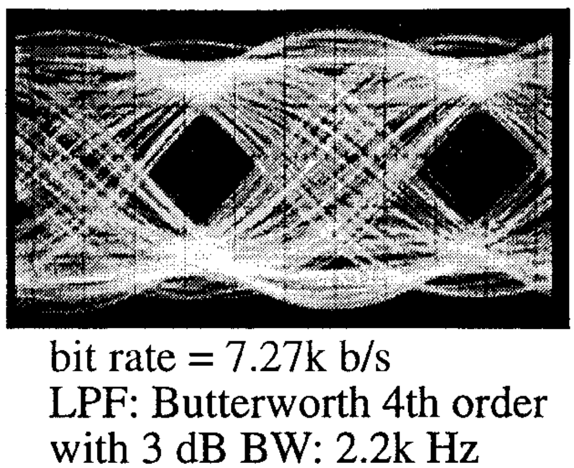


Fig.6 Receiver eye diagram of FQPSK-L

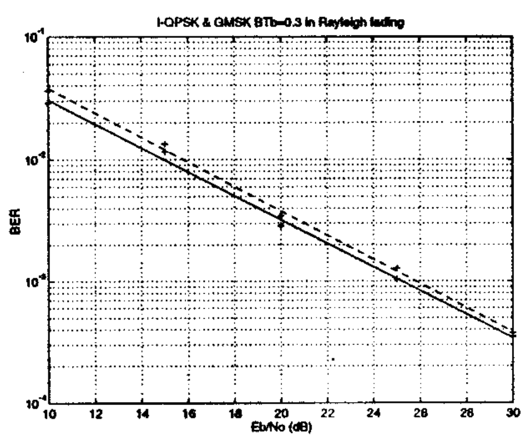


Fig.7 BER performance of FQPSK-L and GMSK BTb=0.3 as function of E_b/N_o in Rayleigh fading channel. FQPSK-L outperforms GMSK by 0.8 dB.

4. Conclusion

New constant envelope modulation schemes and architectures for QPSK by cubic spline interpolation methods which increase spectral efficiency and power efficiency are presented. Being a constant envelope modulation, FQPSK-L can be operated in class C power amplifier without spectrum regrowth. FQPSK-L has a narrower spectrum than that of GMSK with BTb=0.3 till 73 dB attenuation. Especially, it is 20% to 30% more spectrally efficient than that of GMSK with BTb=0.3 from 40 dB to 70 dB attenuation. In Rayleigh fading, FQPSK-L even has better performance than that of GMSK BT_b=0.3.

Another significant advantage of FQPSK-L is that it can use coherent, non-coherent differential and discriminator demodulation. Discrete spectral components in FPQSK-L can be used for carrier recovery, symbol time recovery, and slow fading compensation. Thus, FQPSK-L is an excellent scheme for wireless and satellite communications which require high spectral and power efficiency.

5. Acknowledgment

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