Power and Spectrally Efficient M-ARY QAM Schemes for Future Mobile Satellite Communications

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Abstract

An effective method to compensate nonlinear phase distortion caused by the mobile amplifier is proposed. As a first step towards the future use of spectrally efficient modulation schemes for mobile satellite applications, we have investigated effects of nonlinearities and the phase compensation method on 16-QAM. The new method provides about 2 dB savings in power for 16-QAM operation with cost effective amplifiers near saturation and thereby promising use of spectrally efficient linear modulation schemes for future mobile satellite applications.

1 INTRODUCTION

Mobile Satellite (MSAT) communications represent one of the most vital and key areas of the mobile communications field. As a result of extensive research, MSAT terminals accommodating speeds of 4.8 kb/s in 5 kHz bandwidth to provide good quality voice, have been developed. The need to use cost effective non-linear amplification, as well as robust operation to overcome the strong fading behaviour of the MSAT channel has forced the use of MCPSK type signal format (8PSK signal constellation are presently used). Also, to provide better power efficiency, the use of coding (in the form of trellis coded modulation (TCM)) has been applied [1].

Although the present spectral efficiency of 1 b/s/Hz (achieved by 4.8 kb/s in 5 kHz) may be sufficient for today's demand, it is quite certain that higher efficiency is required in the near future to provide new services and accommodate more users in the already congested radio frequency band. The natural direction is to consider the development of MSAT schemes based on the use of M-ary QAM signal formats. However, a few problems related to the mobile satellite channel has to be addressed. They include: Amplifier nonlinearities, fading, doppler effects, phase noise, etc. In [2] feasibility of multilevel signaling scheme (16-QAM) is demonstrated in land-mobile fading channels by employing a Rayleigh fading compensator. It is also shown that fade compensated 16-QAM does not suffer from error floors as compared to conventional GMSK. Use of 16-QAM modulation scheme for satellite channels has also been investigated in [3], [4].

The effect of nonlinearities in the form of AM/AM and AM/PM distortions have to be considered seriously as they can produce high levels of signal distortion and interference. This problem has to be addressed in the MSAT terminal design to employ cost effective amplifiers. For operation near saturation, the performance of QAM schemes is dictated mainly by the outermost states. The degradations are caused by the phase rotation and amplitude compression of the various states with respect to their nominal positions. Most of the amplifiers exhibit fairly linear AM/AM characteristic if the output is backed slightly from saturation. However, their AM/PM characteristics are significantly nonlinear. As the system performance is mainly controlled by the phase change between the operating point (where the average power of the signal is present) and the point at which the outermost state lies, it is necessary to equalize the nonlinear phase to operate near saturation. The immunity of the QAM schemes can be expressed by their phase margins, where phase margin is defined as the phase rotation required from the nominal value to create the irreducible error floor. For 16-QAM, the phase margin is 16.87 degrees [7].

To overcome nonlinear distortion several methods are possible. For linear modulation schemes, the popular methods employed are, predistortion [5] and new signal constellations [6]. For smaller constellations ($<$ 64 states), predistortion method either in analog or digital form is employed and for larger constellations ($>$ 64 states), both methods are used.

In this paper, we propose the use of 16-QAM for future MSAT terminals. Towards this direction, we first analyze 16-QAM transmission in a Gaussian channel employing a cost effective amplifier in a mobile terminal. A novel phase compensation method to overcome the AM/PM distortion will be introduced. Next, the performance of this scheme is evaluated in the mobile satellite channel environment by using Rician fading model. The performance is analyzed using computer simulation. Organization of the paper is as follows: In section 2, the communication system model is described. In section 3, the performance results are discussed and finally, in section 4, conclusions are presented.

2 SYSTEM MODEL

Block diagram of the communication system is shown in Fig. 1. The transmitter consists of a signal mapper, a spectral shaping filter and a modulator. A square root ($\alpha = 0.5$) Nyquist I filter is equally apportioned between transmitter and receiver. A class-AB amplifier [5] is used as a model to simulate the mobile terminal nonlinear amplifier characteristic. Computer simulation is conducted using an equivalent quadrature baseband model. In order to account for the level compression due to the nonlinear AM/AM characteristic of the amplifier while operating near saturation, an adaptive threshold detector is employed at the receiver [7].

The transmitted signal $x_T(t)$ can be expressed as:

$$x_T(t) = Re\{b(t)\}e^{j\omega_c t} \tag{1}$$

where $b(t) = b_I(t) + jb_Q(t)$ is the filtered complex baseband signal and ω_c is the carrier frequency. The received signal $x_r(t)$ can be written as:

$$x_r(t) = Re\{c(t)x_T(t)\}e^{j\omega_c t} + n(t) \tag{2}$$

where $c(t)$ represents the fading process and $n(t)$ is the additive Gaussian noise. In the present case, the fading process is Rician in nature.

The received complex baseband signal expressed by Eq.(2) can be obtained by demodulating with a local oscillator whose frequency is ω_c. It is assumed for the analysis, that good estimates of the carrier phase and symbol timing are available at the receiver. The demodulated in-phase and quadrature signals are sampled and passed on to the threshold comparators in the receiver. For a specified power of white Gaussian noise at the threshold detector input, the error probability of the i^{th} symbol with respect to the in-phase channel is computed as follows:

$$p^I_{e_i} = \begin{cases} \frac{1}{2} erfc \frac{Abs(I_i) - S^I_{i_1}}{\sigma\sqrt{2}}, & i = \pm(2N-1) \\ \frac{1}{2}[erfc \frac{Abs(I_i) - S^I_{i_1}}{\sigma\sqrt{2}} + erfc \frac{S^I_{i_2} - Abs(I_i)}{\sigma\sqrt{2}}], & i = \pm1, \pm3, ..., \pm(2N-3) \end{cases} \quad (3)$$

where I_i is the magnitude of the i^{th} received sample and $S^I_{i_1}$ and $S^I_{i_2}$ are the lower and upper thresholds. $S^I_{i_1}$ and $S^I_{i_2}$ are optimized to lie in the middle of the each eye to minimize the effect of signal distortion. The total symbol error probability for a sequence of N symbols is calculated as

$$P^s_{e_g} = \frac{1}{N} \sum_{i=1}^{N} (p^I_{e_i} + p^Q_{e_i} - p^I_{e_i} p^Q_{e_i}) \quad (4)$$

The error performance in a Rician fading channel can be computed as follows:

$$P_e = \int P^s({}_{e_g}/r) f(r) dr \quad (5)$$

where $f(x)$ is the probability density function for Rician channel and r is the gain attenuation applied to the signal by the fading. $f(x)$ for $x > 0$ is given by [8]

$$f(x) = 2x(1+K)e^{-K} e^{-(1+K)x^2} I_o(2x\sqrt{K(1+K)}) \quad (6)$$

where K is the ratio of specular to diffuse power and $I_o(x)$ is the zero order modified Bessel function of the first kind. For MSAT channels, K=10 dB has been considered [8].

In this paper, we propose a simple and effective method to cancel the effect of AM/PM distortion due to the amplifier, thereby enabling the operation of the amplifier closer to saturation. A block diagram of the proposed method is shown in Fig. 2. By using look-up tables, where the data regarding the relationship between the sampled amplifier input envelope and amplifier phase output are stored,, we can predistort the carrier phase at the amplifier input and thereby effectively canceling the AM/PM distortion.This can be effected by providing a phase correction to the transmitter local oscillator as shown in Fig. 2.

3 PERFORMANCE RESULTS

Error performance results in a Gaussian channel is shown in Fig. 3 for phase uncompensated and phase compensated operation. The transmitter is operated at 3 dB output backoff from saturation. It can be observed that by compensating the AM/PM distortion, it is possible to operate with about 2 dB less CNR which is a significant saving in power. The effect of AM/PM compensation can be seen in the signal state space diagrams shown in Figs. 4 & 5. It can be seen that in both cases the outermost states are compressed due to operation near saturation. However, in Fig. 4 the outer states are distorted due to nonlinear phase rotation as only the average phase at the operating point is compensated, while in Fig. 5 the all states are in their nominal positions thereby providing greater decision distance and improved error performance. The BER performance of 16-QAM in Rician channel (K=10 dB) is also shown in Fig. 3. There is modest penalty in terms of power, but no error floor is observed over the range of observation.

The effect of Doppler shift due to the relative motion between the transmitter and the receiver has not been covered in this paper, as it has been demonstrated in [2] that it can be easily compensated using compensation techniques without significant performance degradations.

4 CONCLUSIONS

A simple and effective method to compensate the nonlinear phase distortion due to the amplifier is proposed. As a first step towards the future use of spectrally efficient modulation schemes for mobile satellite applications effects of nonlinearities on 16-QAM has been investigated. It is shown that about 2 dB power savings in transmitter power can be achieved by compensating phase nonlinearities for 16-QAM. We are confident that this method could be very effective in future mobile satellite systems while employing spectrally efficient modualtion schemes.

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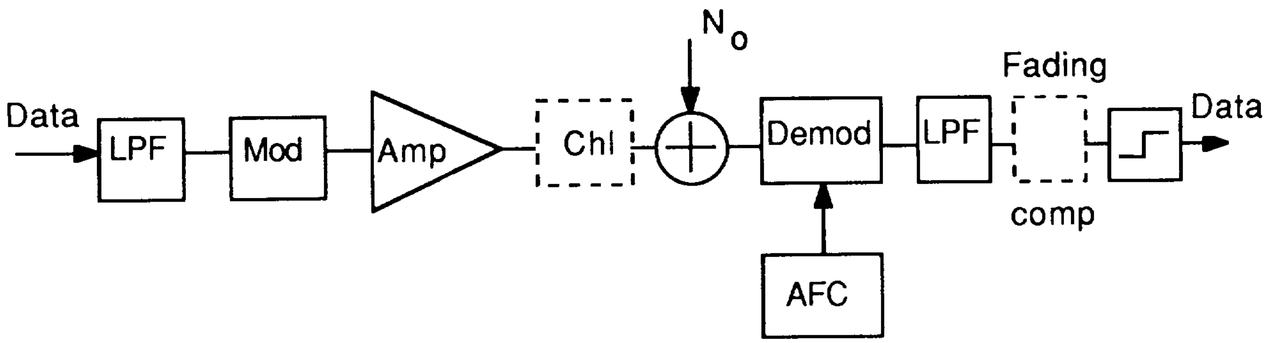

Figure 1. System Model with Linearized Amplifier & Coherent Demodulator

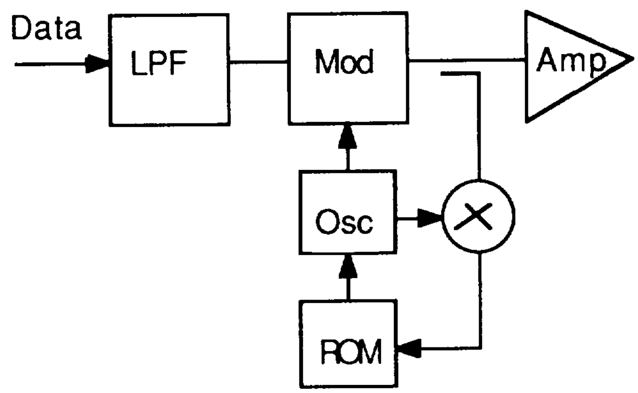

Figure 2. Nonlinear Phase Compensation Method

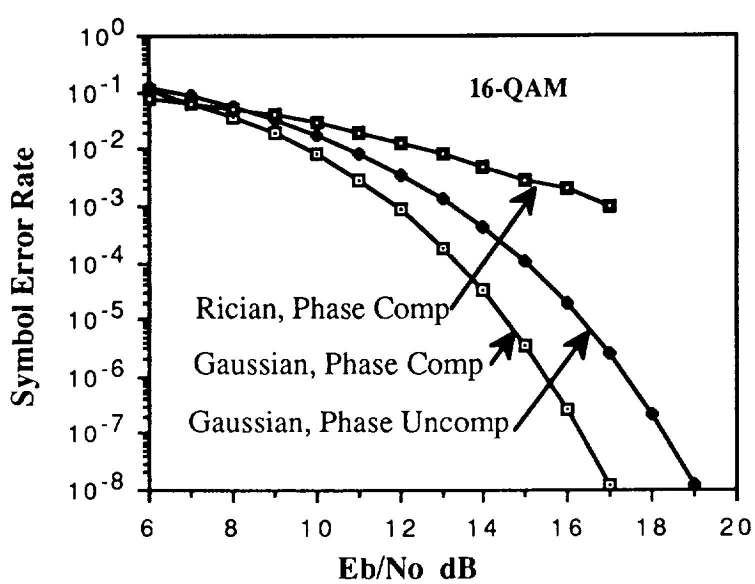

Figure 3. Error Performance of 16-QAM

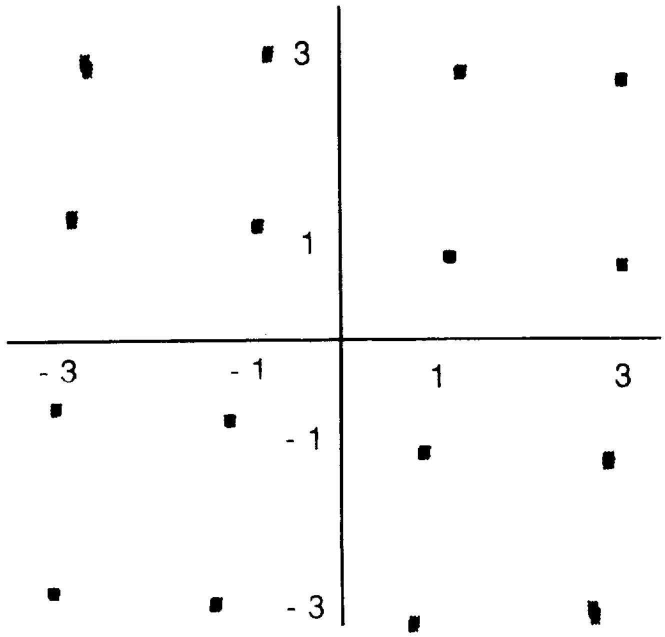

Figure 4. Signal State Space Diagram of 16-QAM Without Phase Compensation

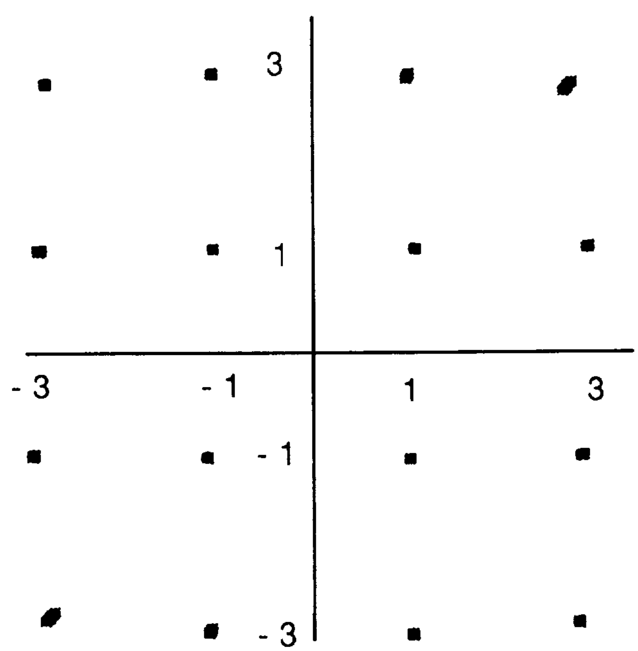

Figure 5. Signal State Space Diagram of 16-QAM with Phase Compensation