PERFORMANCE OF 16-ARY DEQAM SIGNALLING WITH A PRE-ROTATED CONSTELLATION THROUGH NONLINEAR SATELLITE CHANNELS

S.W. CHEUNG and A.H. AGHVAMI

Communications Research Group,
Department of Electronic and Electrical Engineering
King's College London (University of London)

Abstract: This paper investigates the effects of AM-AM and/or AM-PM conversions of a high power amplifier (HPA) on the performance of a bandlimited 16-ary differentially encoded quadrature amplitude modulated (16-ary DEQAM) system in the presence of additive white Gaussian noise. The results obtained by computer simulation show that a combination of moderate output backoff from saturation of the HPA and pre-rotation of the transmitted signal constellation can considerably improve the system performance. Finally, the performance of the proposed system is compared to that of a 16-ary DEQAM system employing an RF predistorter.

1. Introduction

Recent increasing demands for the channel capacity and RF spectrum of digital satellite radio systems have led to the research on the possible application of highly spectrally efficient modulation techniques for such systems[1 - 5]. Among these modulation techniques, 16-ary quadrature amplitude modulated (16-ary QAM) signals, because of their relative simplicity of implementation and good error performance through linear channels, have recently received attention[3 - 5]. However, because of the non-constant nature of their envelopes, 16-QAM signals are very sensitive to the nonlinear effects of a typical satellite HPA. It has been shown that[4 - 5] the performance of 16-ary QAM transmission through a satellite channel is substantially degraded due to the AM-AM and AM-PM conversion effects of the HPA operating at or near saturation unless the HPA is either operated at a large backoff from saturation or pre-distortion techniques are used.

In this paper, the effects of AM-AM and/or AM-PM conversions of the HPA of a satellite system, on the performance of a bandlimited 16-ary differentially encoded quadrature amplitude modulation (16-ary DEQAM) signal, are investigated. The results of the investigation lead to the introduction of a simple pre-rotation technique which considerably improves the system performance.

2. Model of the System

The model of the digital system studied here is shown in Fig. 1. The information to be transmitted is carried by the binary digits $\{s_i\}$, where $s_i = 0$ or 1. When the encoder has received s_{4i}, s_{4i+1}, s_{4i+2} and s_{4i+3}, it differentially encodes and then maps[5] these into the corresponding coded signal-elements $q_{0,i}$ and $q_{1,i}$, where $q_{0,i} = \pm 1$ or ± 3 and $q_{1,i} = \pm 1$ or ± 3. The symbols are such that the resulting 16-ary DEQAM signal elements at the output of the transmitter (Fig. 1) are differentially encoded. Each premodulation lowpass filter has an impulse response $p(t)$, so that the signals at the outputs of the inphase and quadrature premodulation filters in the transmitter of Fig. 1 are

$$\sum_i q_{0,i}\, p(t - iT) \quad \text{and} \quad \sum_i q_{1,i}\, p(t - iT)$$

respectively, where T is the symbol period.

The modulation process is linear. The IF filter is a real surface acoustic wave (SAW) bandpass filter (Plessey, No. BP1103), with a linear phase characteristic and a frequency response as shown in Fig. 2. The 16-ary DEQAM signal at the output of the IF filter is fed through an upconverter, that changes the carrier frequency from f_c Hz (at IF) to that required for the transmitted signal, thus permitting the modulation process itself to be carried out at the lower frequency of f_c Hz. The final stage of the transmitter is an HPA, which feeds the transmitter output 16-ary DEQAM signal to the antenna. Three assumed HPA's, called HPA1, HPA2 and HPA3 are used in tests. HPA1 has the nonlinear AM-AM and AM-PM characteristics

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given in Fig. 3. It introduces both amplitude and phase distortions into the transmitted signal. The maximum signal level passed by HPA1 is set to unity and is called the saturation level. HPA2 has the same nonlinear AM-AM characteristic given in Fig. 3, but a constant AM-PM characteristic. Thus it introduces only amplitude distortion and no phase distortion into the transmitted signal. While HPA3 has the same nonlinear AM-PM characteristic given in Fig. 3, it has a linear AM-AM characteristic even above saturation. It introduces only phase distortion and no amplitude into the transmitted signal. HPA2 and HPA3 are used to investigate the individual nonlinear AM-AM and AM-PM conversion effects of HPA1 on the transmitted signal. For the same input back off (IBO), HPA1 and HPA2 have the same output back off (OBO). For HPA3, with a given IBO, the OBO value is dependent upon the slope of the AM-AM characteristic.

The transmission path, from the output of the HPA to the input of the receiver (Fig. 1), is assumed here to be linear. In the model of the system used for the tests, the transmission path is assumed to introduce no attenuation, distortion or noise, and the transmission delay is, for convenience, ignored. Thus the received 16-ary DEQAM signal is taken to be the same as the corresponding transmitted signal. Stationary white Gaussian noise is assumed to be added to the 16-ary DEQAM signal at the receiver input.

The output signal from the input amplifier is fed through the down-converter, which changes the carrier frequency back to IF. An IF filter, with the same characteristics as that at the transmitter, then bandlimits the received signal before the latter is demodulated coherently. The reference carriers used for demodulation are taken to have the correct frequency and phase, and the post-demodulator lowpass filters have the same impulse response p(t) as the premodulation lowpass filters in the transmitter. The two demodulated baseband signals, at the outputs of the lowpass filters, are sampled at the correct time-instances $\{iT\}$, once per received 16-ary DEQAM signal element, so that ideal demodulation and sampling is achieved. Furthermore, in the absence of any nonlinear distortion introduced by the HPA, ideal matched filter detection is also achieved here. The samples of the two demodulated baseband signals are fed to the associated threshold detectors, whose output signals are the detected symbols $\{q'_{0,i}\}$ and $\{q'_{1,i}\}$. These are fed to the decoder, which operates on them to give the corresponding detected binary digits $\{s'_i\}$. In the absence of errors, $s'_i = s_i$, for all $\{i\}$.

In the computer-simulation model of the system, it is necessary to use the equivalent baseband signal in place of the modulated-carrier signal. To test the effects of the IF filters and HPA on the transmitted signal, the model of Fig. 4 is used in the simulation, where either of the two switches A and B is closed.

3. Computer-Simulation Tests

3.1 Basic Assumptions

Computer-simulation tests have been carried out on the transmission system of Fig. 1, where the HPA may be HPA1, HPA2 or HPA3. In every case the equivalent baseband model has been used. The signal/noise ratio is taken as ψ dB,

where $$\psi = 10 \log_{10}\left(\frac{E_b}{N_o}\right).$$

E_b is the average transmitted energy per bit and N_o is the one-sided power spectral density of the additive white Gaussian noise at the input of the receiver. In all tests, the lowpass filters in the transmitter and receiver of Fig. 4 are the same. Furthermore, they are such that the resultant frequency response of the transmitter and receiver lowpass filters in cascade, and in the absence of any nonlinear distortion, has a raised cosine shaping with a rolloff of 50%. The impulse response of each of the lowpass filters has infinite length. However, a truncated portion of duration 4T of the ideal impulse response is used in simulations. Results have shown that[5] this causes a negligible degradation in performance at bit error rates around 10^{-5}, relative to the ideal 16-ary DEQAM system.

3.2 Results and Discussion

Figure 5 shows the influence of the HPA on the eye diagram of the inphase demodulated signal in the receiver of Fig. 4. In Fig. 5a, the switch 'A' is closed, whereas in Figs. 5b, 5c and 5d, the switch 'B' is closed with the use of HPA1, HPA2 and HPA3, respectively. It is evident that at a given backoff, HPA1 causes more signal distortion than does HPA2 or HPA3, and HPA2 reduces the eye openings of the signal more than does HPA3.

Figure 6 illustrates the bit error rate performances of the system shown in Fig. 4 with the switch 'B' closed and different degrees of backoff in the HPA (HPA1, HPA2 or HPA3). It can be seen that, the degradations in tolerance to noise, at a bit error rate of 10^{-4}, with 5 dB OBO in HPA1, is about 4.9 dB, relative to that of an ideal 16-ary DEQAM system. If the AM-PM nonlinear distortion in the signal is removed, i.e. replacing HPA1 by HPA2, the degradation is reduced to about 1.1 dB (a reduction of about 3.8 dB), while if the AM-AM nonlinear distortion in the signal is removed instead, i.e. replacing HPA1 by HPA3, the degradation is reduced to about 0.8 dB (a reduction of about 4.1 dB). With 4 dB OBO in HPA1, the degradation in tolerance to noise of the system is about 10 dB, at a bit error rate of 10^{-4}, relative to that of an ideal 16-ary DEQAM system. The degradation is reduced to 2.8 dB or 1.2 dB, through replacing HPA1 or HPA3, respectively. The degradation caused by the nonlinear AM-AM and AM-PM conversion effects is much greater than the sum of the degradations caused by the individual nonlinear AM-AM and AM-PM effects. This is more obvious at low backoff values.

The above implies that, if either the AM-AM or AM-PM conversion effects of the HPA is removed or reduced, a very significant improvement in performance may be achieved. Figure 7 shows the received signal-space vectors, at the time instances $\{iT\}$, at the outputs of the post-demodulation filters in the system of Fig. 4. Figure 7a corresponds to when the switch 'A' is closed, whereas Fig. 7b corresponds to when the switch 'B' is closed with 5 dB OBO in the HPA1. Comparing Fig. 7a to Fig. 7b, it can be seen that the signal-space vectors with amplitude of $\sqrt{10}$ have less distortion than those with $\sqrt{18}$ and $\sqrt{2}$. The lengths of the signal-space vectors with amplitude $\sqrt{18}$ are reduced, while those with amplitude $\sqrt{2}$ are expanded. These are caused by the AM-AM conversion effect in the HPA. It can also be seen that the signal vectors with amplitudes of $\sqrt{18}$ and $\sqrt{2}$ are rotated clockwise and anticlockwise, respectively, by certain degrees. These are caused by the AM-PM conversion effect in the HPA. Figure 7b also shows that these AM-AM and AM-PM effects have reduced the distances, of the signal-space vectors with amplitude $\sqrt{18}$, from the decision threshold significantly, hence the nonlinear effects cause significant degradation in tolerance to noise (10 dB, at a bit error rate of 10^{-4}) to the signal (Fig. 6). If the AM-PM signal distortion is removed from the signal-space vectors, i.e. replacing HPA1 by HPA2 in Fig. 4, Fig. 7c replaces Fig. 7b, while if the AM-AM signal distortion is removed from the signal-space vectors, i.e. replacing HPA1 by HPA3 in Fig. 2, Fig. 7d replaces Fig. 7b. Comparing Fig. 7b to Figs. 7c and 7d, it can be seen that, the distances, of the signal-space vectors with amplitude $\sqrt{18}$, from the decision threshold, are significantly increased, i.e. an improvement on the system performance as already shown in Fig. 6.

In Fig. 7d, the signal-space vectors with amplitudes $\sqrt{18}$ and $\sqrt{2}$ are rotated clockwise and anticlockwise, respectively, by certain angles. The values of these angles are dependent upon the AM-PM characteristic of the HPA. Therefore, with a prior knowledge of the AM-PM characteristic of the HPA, if the signal elements $q_{0,i}$ and $q_{1,i}$, before lowpass filtering at the transmitter, are pre-rotated with the same amounts of angles but in the opposite directions done by the HPA, the effect of the AM-PM can be reduced and hence an improvement in the system performance can easily be achieved. Figure 7e shows the received signal-space vectors using the pre-rotation method. The performances of the signal, with the pre-rotation method and different degrees of OBO, are also shown in Fig. 6. It indicates that, with 5 dB OBO in the HPA1 and at a bit error rate of 10^{-4}, the degradation in tolerance to noise is about 1.6 dB, compared to 4.9 dB when pre-rotation is not used. An improvement of 3.3 dB has been achieved. In fact, at this backoff, there is very little difference in performances between the pre-rotation method and HPA2, hence the AM-PM signal distortion in the received signal-space vectors is nearly eliminated. The degradation of 1.6 dB is caused mostly by the AM-AM conversion effect of the HPA1. However, with 4 dB OBO in the HPA1 and at the same bit error rate, the method has a degradation of about 3 dB, compared to 10 dB when pre-rotation is not used. Obviously, the method is better when used at high OBO values.

The performance of the signal with 4 dB OBO and RF predistortion[4] is shown in Fig. 6, which indicates that pre-rotation is about 2 dB worse than that of RF predistortion. This is because the overall amplitude characteristic of the RF predistorter and HPA is actually linear up to saturation and the overall phase characteristic has almost zero phase shift, irrespective of the input power, while the pre-rotation method does not eliminate the AM-AM conversion effect of the HPA at all. However, pre-rotation is still cost effective because the hardware implementation is extremely simple. All it requires is a different set of signal constellations used at the transmitter.

4. Conclusions

The effects of the AM-AM and/or AM-PM conversions of a satellite HPA, on the performance of a 16-ary DEQAM transmission, in the presence of additive white Gaussian noise, have been examined. The results show that, the degradation due to the AM-AM and AM-PM conversion effects of the HPA tested is much less than that of the sum of the degradations caused by the individual AM-AM and AM-PM conversion effects. Also, the AM-AM signal distortion causes more degradation than does the AM-PM signal distortion, under the same assumed conditions.

With pre-rotation and moderate output backoff values of the HPA, the AM-PM distortion in the received signal-space vectors can nearly be eliminated. The results of the study show that, at a 5 dB OBO in the HPA and at a bit error rate of 10^{-4}, the system degradation is about 4.9 dB, relative to that of an ideal 16-ary DEQAM system. However, if pre-rotation is used, the degradation is reduced to 1.6 dB.

5. Acknowledgement

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6. References

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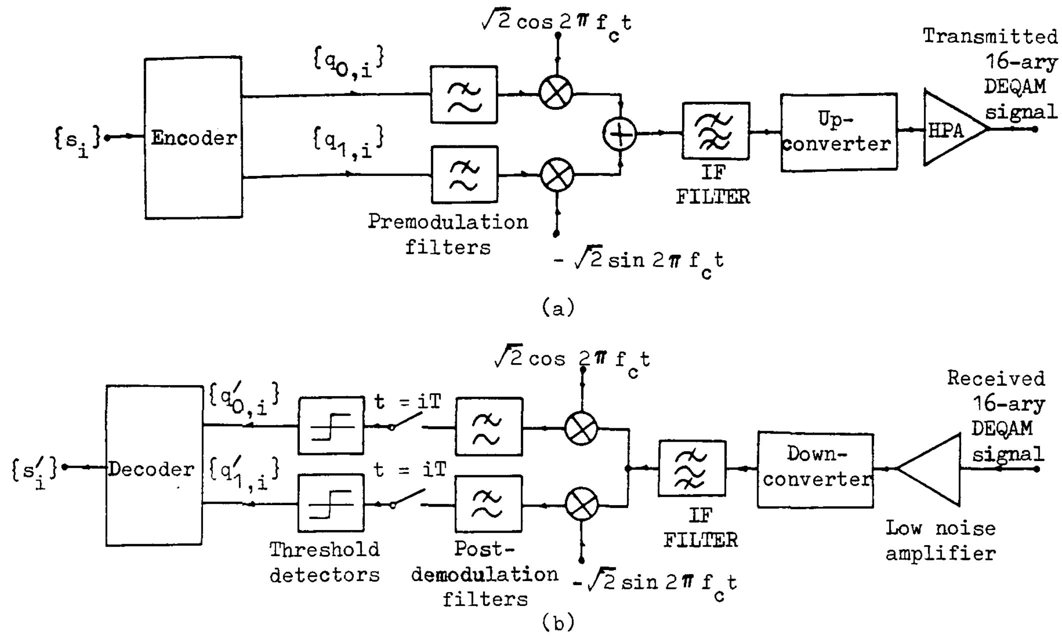


Fig. 1 Block diagram of the system. (a) Transmitter, (b) Receiver.

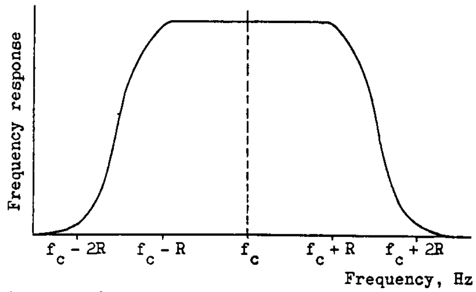


Fig. 2 Frequency response of each IF filter

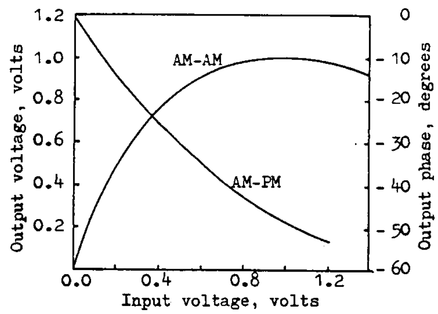


Fig. 3 Characteristics of the HPA1

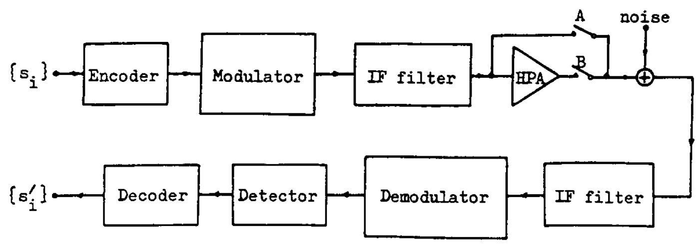


Fig. 4 Model of the system, with a linear or nonlinear satellite channel

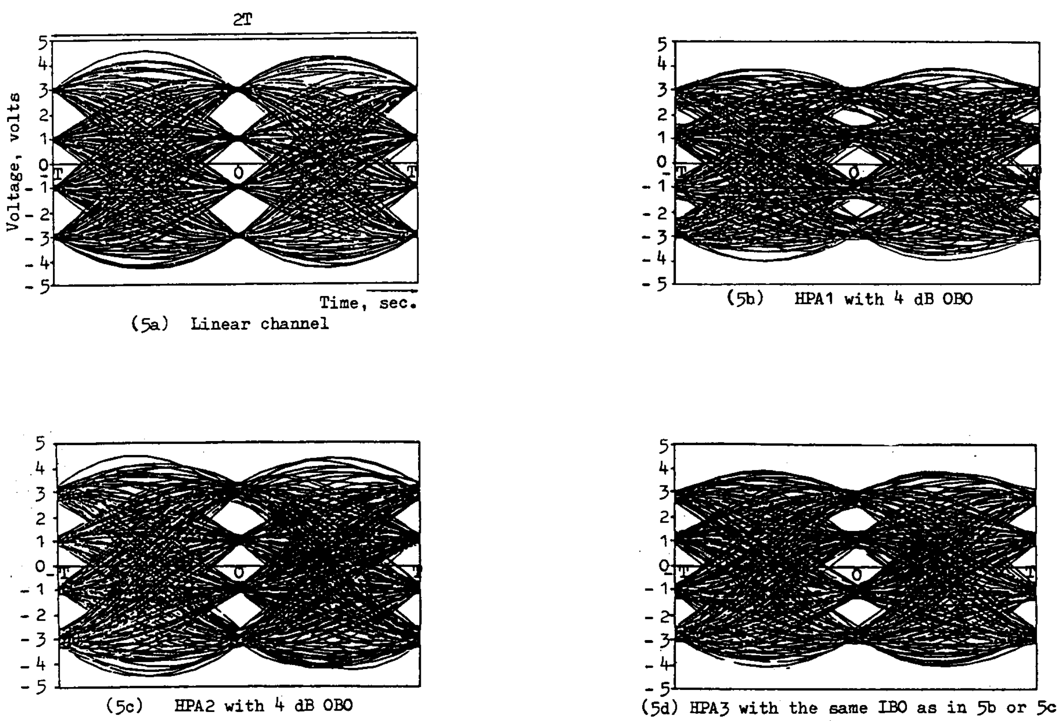


Fig. 5 Eye diagrams of one of the components of the signal

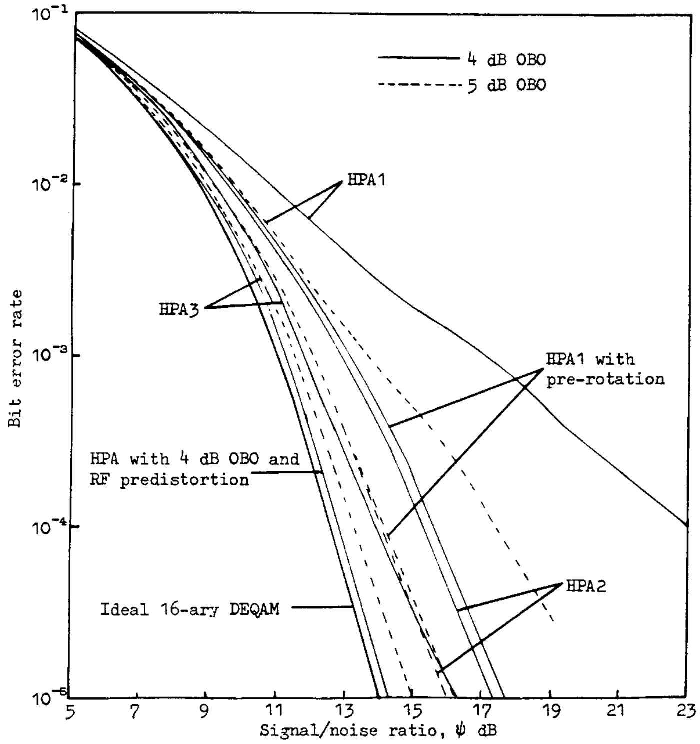
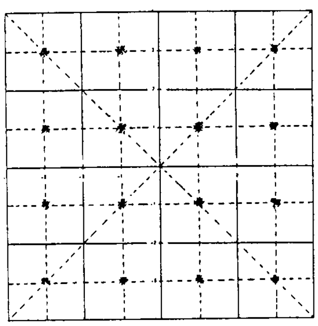
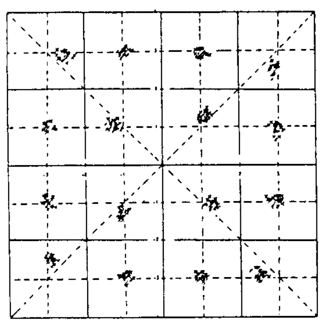


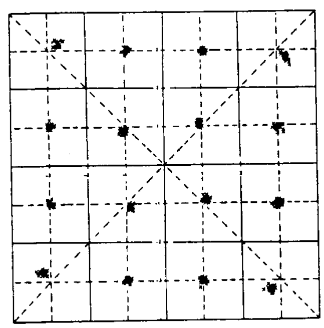
Fig. 6 Performances of the signal with HPA1, HPA2 and HPA3



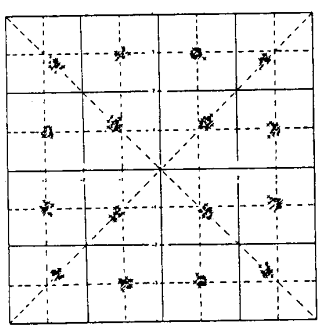
(7a) Linear channel



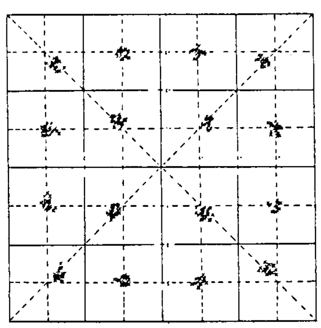
(7b) HPA1 with 5 dB OBO



(7c) HPA2 with 5 dB OBO



(7d) HPA3 with the same IBO as in (7b) or (7c)



(7e) HPA1 with 5 dB OBO and pre-rotation

Fig. 7 Received signal-space vectors.

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