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

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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 \( s_{4i} \) and \( s_{4i+1} \), it differentially encodes and then maps these into the corresponding coded signal-elements \( q_{0,1} \) and \( q_{1,1} \), where \( q_{0,1} = \pm 1 \) or \( \pm 3 \) and \( q_{1,1} = \pm 7 \Delta f = 3 \). 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

\[
\sum_{t} q_{0,1} p(t - iT) \quad \text{and} \quad \sum_{t} q_{1,1} p(t - iT)
\]

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. AP103), 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.
While HPA3 has the same nonlinear AM-PM 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-AM 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 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 [5], 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 \( s_i^* \) and \( s_i^\prime \). These are fed to the decoder, which operates on them to give the corresponding detected binary digits \( s_i \). In the absence of errors, \( s_i = s_i^\prime \), 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. 5 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 \( \psi dB \),

\[
\psi = 10 \log_{10} \left( \frac{E}{N_0} \right) \tag{46}
\]

where \( E \) is the average transmitted energy per bit and \( N_0 \) is the one-sided power spectral density of the additive white Gaussian noise at the input of the receiver. In all tests, the low-pass 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 \( 10^{-4} \), 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 0.8 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 OSO in HPA1, the degradation in tolerance to noise of the system is about 10 dB, at a bit error rate of $10^{-4}$. Figure 7 shows the received signal-space vectors, at the time instances $\{T_1\}$, 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 OSO in the HPA1. Comparing Fig. 7a to Fig. 7b, it can be seen that the signal-space vectors with amplitude $\sqrt{\beta}$ have less distortion than those with $\sqrt{\theta}$ and $\sqrt{\gamma}$. The lengths of the signal-space vectors with amplitude $\sqrt{\gamma}$ are reduced, while those with amplitude $\sqrt{\beta}$ 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 $\sqrt{\theta}$ and $\sqrt{\beta}$ are rotated clockwise and anticlockwise, respectively, by certain degrees. These are caused by the AM-AM and AM-PM conversion effects in the HPA. If the AM-PM signal conversion effect in the HPA is removed using the pre-rotation method, the degradation caused by the AM-AM and AM-PM effects in the HPA can be reduced. This is because the overall amplitude characteristic of the HPA is actually linear up to the saturation power level, and the overall phase characteristic has almost zero phase shift, irrespective of the input power, while the overall phase characteristic has almost zero phase shift, irrespective of the input power. However, the pre-rotation method does not eliminate the AM-AM and AM-PM conversion effects 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 conversion effect.

51.6.3.
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


[5] CHEUNG, S.W. and AGHVALI, A.H. 'Performance of a 16-ary DEQAM modem employing a baseband or RF predistorter over a regenerative satellite link'. Submitted to IEE for publication.
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

Fig. 7 Received signal-space vectors.

(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