Reducing the effect of the nonlinear distortion in 16-APSK OFDM system by pilot-based automatic phase shift

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ABSTRACT

The paper proposed a method to reduce the effect of nonlinear distortion in 16-APSK OFDM system, which is a pilot-based automatic phase shift at the receiver. Transmitted pilot is inserted during the OFDM modulation process in the transmitter. When the pilot passes through the HPA, information about the nonlinear distortion of the HPA will be carried. In the receiver, the phase angle is rotated automatically based on the phase difference between the received pilots and the transmitted pilots, without depending on the HPA amplifier or system parameters. When the OFDM system uses the APS-pilot method, the nonlinear distortion reduction performance is approximately the same as in the OAPS method, the empirical formula to calculate OAPS, as well as the preset of OAPS manually at the receiver, is not needed.

Keywords: OFDM; Nonlinear distortion; HPA; APS-pilot.

1. INTRODUCTION

OFDM system (Orthogonal Frequency Division Multiplexing) has the superior advantages of high bandwidth efficiency and the robustness against frequency-selective fading channels, so it is used in many systems such as Digital Video Broadcast-Terestrial (DVB-T), the mobile radio networks 4G, etc. APSK (Ampitude Phase Shift Keying) modulation is widely used in broadcast systems such as digital broadcasting standards, DVB-S2 satellite digital television. These systems require high transmit power, so the nonlinear distortion caused by HPA (High Power Amplifier) for the APSK OFDM system is very serious, leading to a sharp decline in system quality. That causes nonlinear ISI, wrapping the constellation, causing nonlinear noise (inband) and expanding the output signal bandwidth. Therefore, countermeasures of nonlinear distortion caused by HPA have been and are being studied by a lot of scientists.

Countermeasures nonlinear distortion in the transmitter include: using BO (back-off) optimal [1]; using PD (Pre-Distorter) [2, 3]; reducing PAPR (Peak-to-Average Power Ratio) with OFDM systems [4], etc. However, these techniques cannot completely eliminate the effects of nonlinear distortion caused by HPA, especially with M-APSK OFDM and M-QAM OFDM systems. Therefore, measures to reduce nonlinear distortion at the receiver are very necessary. In previous studies, the authors used the OAPS method because it can be performed at the receiver, with relatively high efficiency [5-8]. However, this method has to know in advance the system parameters and HPA parameters. On the other hand, if the system parameters changes (type of HPA, M-APSK modulation level, number of subcarriers in an OFDM symbol, etc.), the preset empirical formula for phase rotation angle will change. Then, this method becomes complicated because it needs many empirical formulas for M-APSK OFDM system. To overcome these shortcomings, we use the method of rotating the received signal phase based on the received pilot value, called the APS-pilot (pilot-based Automatic Phase Shift) method. In this method, the combined phase rotation caused by both the HPA and the channel is calculated and compensated automatically, based on the comparison of the receiving pilot and the transmitting pilot.

The paper, after the introduction, is organized as follows: System model APSK OFDM and APS-pilot method are presented in Sect. 2; Simulation results and discussions are given in Sect. 3; Sect. 4 is used for the conclusion.

2. SYSTEM MODEL AND APS-PILOT METHOD

2.1. System model 16-APSK OFDM

The APSK OFDM system model used for simulation is shown in figure 1.

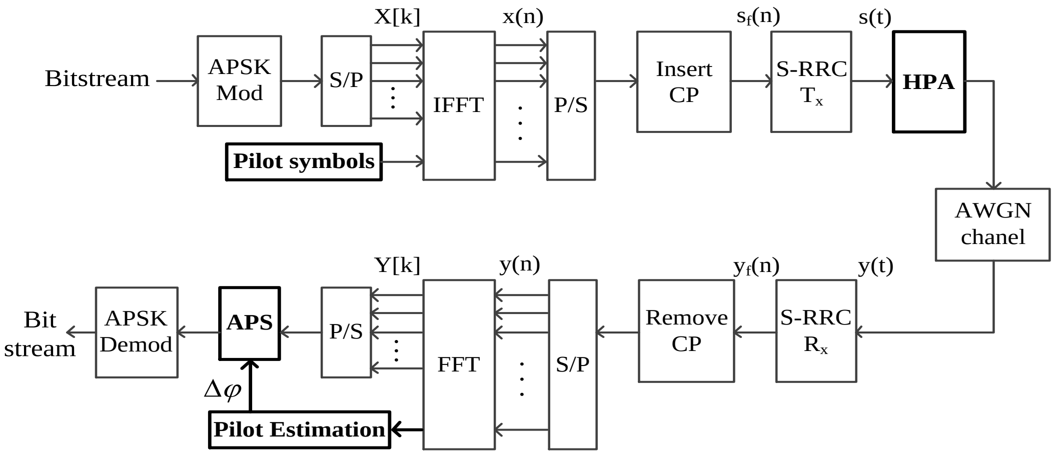


Figure 1. *Surveying model of APSK OFDM system using APS-pilot method.*

The binary bitstream after APSK modulation is divided into multiple substreams by the S/P (Serial/Parallel) converter and OFDM modulated through the IFFT (Inverse fast Fourier transform) converter. The pilot signal will be inserted into the IFFT to reduce the impact of nonlinear distortion caused by HPA. The signal after OFDM modulation inserts a CP (Cyclic Prefix) protection interval for the purpose of preventing ISI (Inter symbol Interference). The signal then passes through a raised cosine square root filter, is HPA amplified and is transmitted on the AWGN (Additive white Gaussian noise) channel.

The receiver performs the opposite functions as performed by the transmitter. Reducing the impact of nonlinear distortion is performed by two blocks: the pilot estimation block and the APS block.

2.2 APS-pilot method

In the OFDM system, the pilot have been used to estimate the transmission channel with high efficiency, so the pilot can be used to reduce the impact of nonlinear distortion caused by HPA on this system [9-11].

The APS-pilot method is implemented as follows: In the transmitter, pilot TX is inserted during the OFDM modulation process. When the pilot passes through the HPA, information about the nonlinear distortion of the HPA will be carried. At the receiver, the pilots obtained from the output of the OFDM demodulator enter the pilot estimation block. This block will calculate the average value of the received pilots as RX pilot, then compare it with TX pilot stored in the receiver to calculate the value $\Delta\varphi$. This value is then fed into the APS block to rotate the received signal phase by an angle $\Delta\varphi$, as shown in the diagram in figure 2. The APS-pilot method helps the receiver to rotate the phase automatically based on the phase difference between the received pilot and the transmitted pilot.

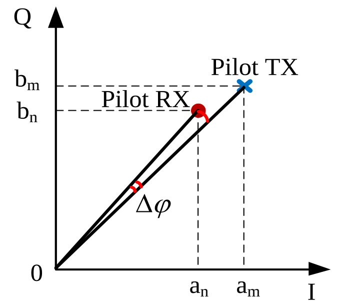


Figure 2. *Determination of Δφ angle of the pilot estimation block.*

3. SIMULATION RESULTS AND DISCUSSIONS

The flow chart of the algorithm is shown in figure 3.

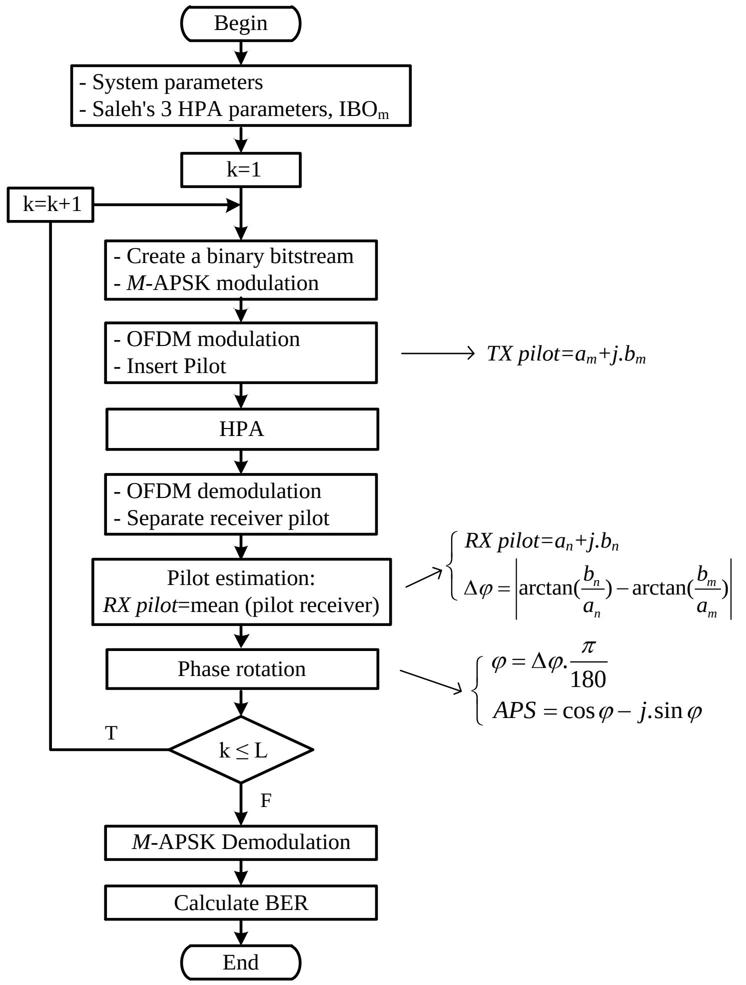


Figure 3. *Flow chart of the algorithm.*

The parameters used in the 16-APSK OFDM system simulation are:

- Number of simulation bits: the number of random bits is 96000000 (a sequence of 2000000 consecutive OFDM symbols, each OFDM symbol consists of 48 bits is modulated in parallel on 12 subcarriers, each subcarrier modulates the baseband 16-APSK means that each sub-symbol period T_u contains 4 bits).

- OFDM modulation: IFFT/FFT set size is 16; The pilot signal is inserted with the distance between pilots being Nps=4; The pilot value used is R1*cos(pi/4)+jsin(pi/4); The CP guard interval is 1/5 of the integration interval length. Transmitter filter and receiver filter: Square root cosine filters: Delay Group= 10, Rolloff = 0.35, F_d = 1, F_S = 8.

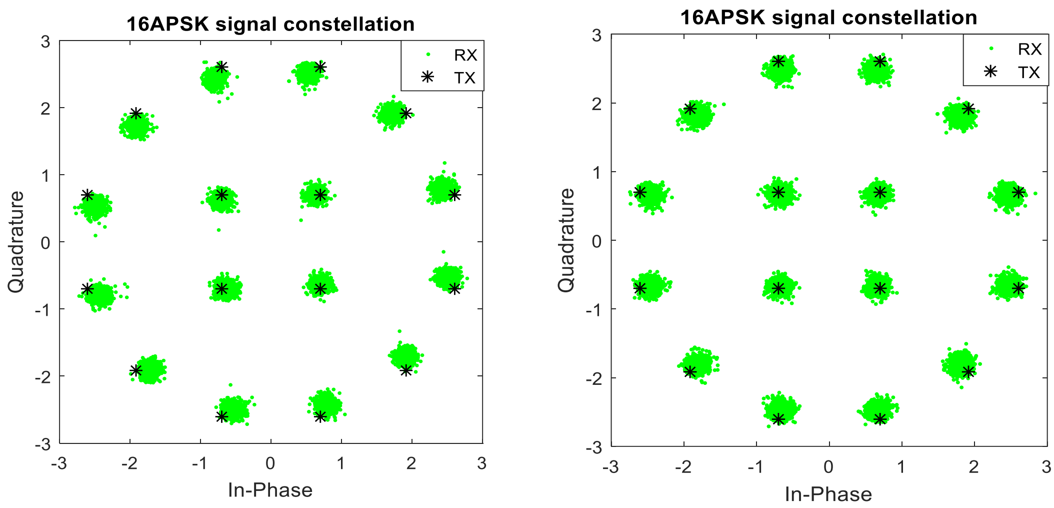
- Because actual HPA data are not available in reference sources, we use TWT (traveling-wave-tube) amplifiers that have been used in previous studies by author Nguyen Quoc Binh [5]. These are HPA267, HPA1371 and HPA1373, these HPAs have parameters of Saleh model and have characteristics given by the manufacturer. The BO value used for OFDM system simulation is the average BO (BO_m).

- In fact, if the channel is multipath fading, when the system uses the APS-pilot method, it will always estimate the combined phase rotation caused by both the HPA and the channel, and then automatically compensate during the equaliser, so the recommendation wouldn't make sense on this channel. Therefore, the channel chosen is AWGN.

We use the Monte-Carlo method with the hope that the simulation results will be highly accurate.

3.1. Select the pilot value to rotate the phase

When the 16-APSK system is affected by nonlinear distortion, causing the received signal points tend to deviate from the ideal points of the transmitted signal in a counterclockwise direction, as shown in figure 4a. When the system using APS-pilot method, the received signals will be automatically compensated for phase by angle $\Delta\varphi$. Therefore, the received signal constellation shifts to the right, as shown in figure 4b.



a) The effects of nonlinear distortions; *b) When the system using APS-pilot method.*

Figure 4. *16-APSK signal constellation, HPA267, BO_m=17.*

In the 16-APSK signal constellation, the nonlinear distortion affecting points with amplitudes R1 and R2 will be different, the small amplitude signal R1 has small nonlinear distortion. The large amplitude signal R2 has large nonlinear distortion, the received signal constellation is unevenly distributed and deviates much to counterclockwise direction of the transmitted signal, as shown in figure 4. When the system uses APS-pilot with amplitude R2, it will not be as effective as amplitude pilot R1, this is proven by simulation results on Matlab, as shown in figure 5.

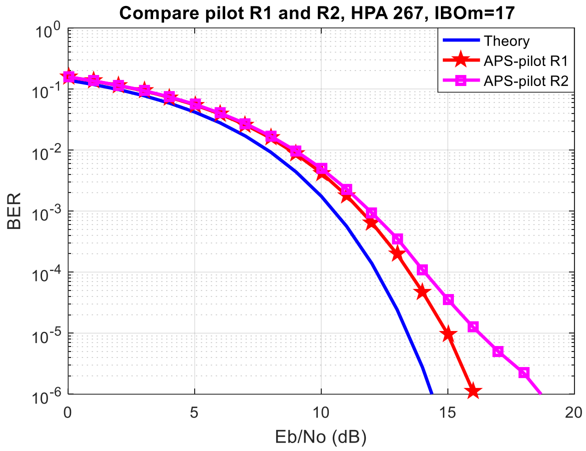


Figure 5. *Compare pilot with amplitudes R1 and R2 in 16-APSK OFDM, HPA267, BO_m=17.*

Figure 5 shows: with HPA267, at BO_m=17, the BER curve when the system uses APS-pilot with amplitude R1 is closer to the ideal BER curve than the BER curve when the system uses APS-pilot with amplitude R2. Thus, the system uses APS-pilot with amplitude R1 is optimal, so we choose the pilot with amplitude R1 in the APS method. In fact, the pilot used for channel estimation in OFDM system. Therefore, we recommend that the *M*-APSK OFDM system using APS-pilot with amplitude R1 to simultaneously reduce nonlinear distortion caused by HPA and estimate the transmission channel.

3.2. The BER curve of 16-APSK OFDM

The advantages of APS-pilot method are shown through the BER curve of the system described in figure 6.

From the simulation results, as shown in figure 6, we see:

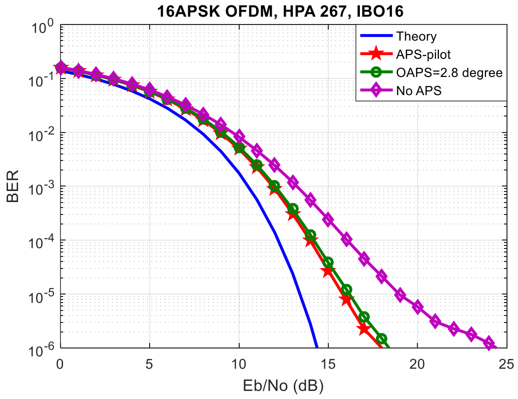
- In case the system does not use APS, the BER curve is far from the BER curve when the system uses APS-pilot.

- The BER curve when the system uses APS-pilot is close to BER curve when the system uses OAPS. This proves that the nonlinear distortion reduction effectiveness of the two methods is almost the same with 16-APSK OFDM system.

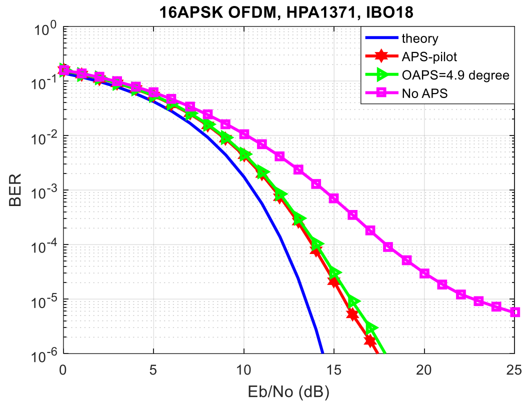
- The BER curve when the system uses APS-pilot is closest to the ideal BER curve without the HPA. This proves that the APS-pilot method can be used to reduce the impact of nonlinear distortion, bringing high efficiency with the APSK OFDM system. Specifically, the value of Eb/N0 at BER=10^{-6} when the system uses and don't use APS-pilot as shown in table 1.

Table 1. *E_b/N_0 value at BER=10^{-6} of the 16-APSK OFDM system.*

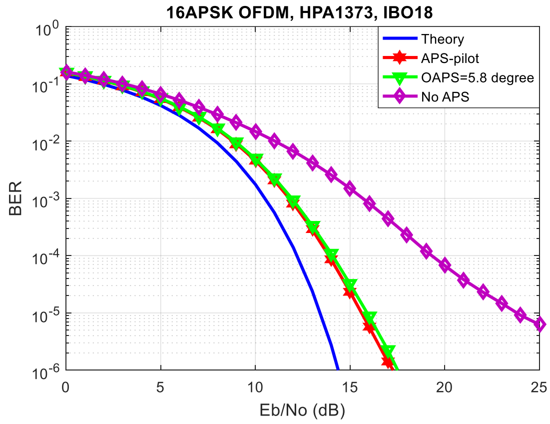
HPA, BO / Method	HPA267, BO_m=16 Eb/N0 [dB]	HPA1371, BO_m=18 Eb/N0 [dB]	HPA1373, BO_m=18 Eb/N0 [dB]
APS-pilot	17.995	17.422	17.280
OAPS	18.400	17.832	17.514
No APS	24.415	signal lost	signal lost



a) HPA267, $BO_m = 16$.



b) HPA1371, $BO_m = 18$.



c) HPA1373, $BO_m = 18$.

Figure 6. *The BER curve of 16-APSK OFDM system with 3HPA.*

3.3. Total degradation of the system

The benefits of phase compensations are measured using an important performance metric, the total degradation (TD), defined as:

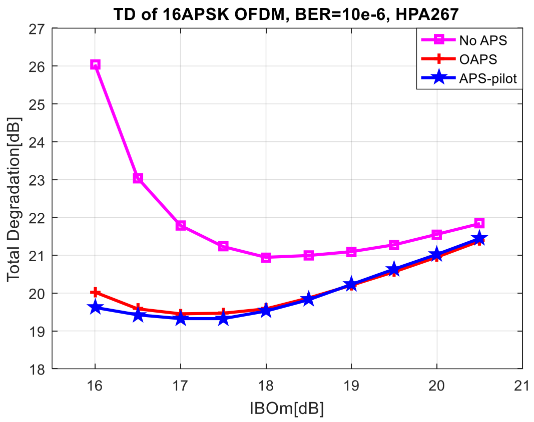
$TD[dB] = E_bN_0^{NL}[dB] - E_bN_0^{L}[dB] + IBO_m[dB]$ where $E_bN_0^{NL}$ is the E_bN_0 value required to achieve a given target BER (in this case is 10^{-6}) on the nonlinear channel, $E_bN_0^{L}$ is the same quantity considering on the linear AWGN channel, and IBO is the input power back off, in OFDM systems using average BO (IBO_m); all quantities are in dB.

Figure 7 presents the variation of TD versus IBO_m for both systems without and with APS-pilot method at 3 HPA. The optimal working point of the system when using APS-pilot method is greatly reduced, as shown in table 2.

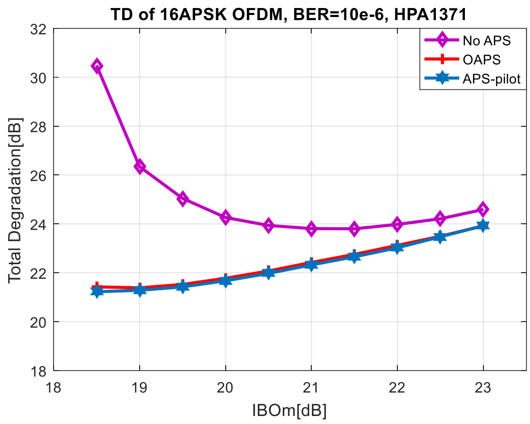
Table 2. *IBO_{opt} of HPA when 16-APSK OFDM system uses APS-pilot.*

HPA / Method	267		1371		1373	
	IBO_{opt}	**TD**	**IBO_{opt}**	**TD**	**IBO_{opt}**	**TD**
APS-pilot	17	19.32	19	21.28	18.5	21.12
OAPS	17	19.45	19	21.38	18.5	21.27
No APS	18	20.945	21.5	23.801	21.5	24.932

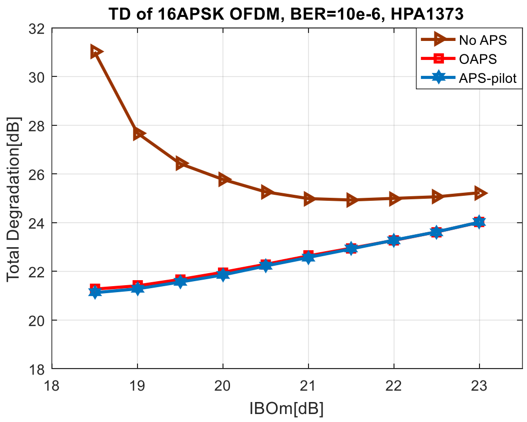
Thus, by using the proposed APS-pilot method, the optimal working point of the system is greatly reduced. It is possible to push the HPA's operating point closer to the saturation point while still maintain the same system performance. In practice, this leads to other beneficial consequences such as power usage effectiveness, space usage efficiency, service life, reliability,... However, this method has a limitation because loss of a small portion of bandwidth due to having to insert pilots with large enough quantities to ensure accurate estimation.



a) HPA267.



b) HPA1371.



c) HPA1373.

Figure 7. *TD of 16-APSK OFDM system at BER=10^{-6} with 3HPA.*

4. CONCLUSIONS

The paper proposes a method to reduce the impact of nonlinear distortion, which is pilot-based automatic phase rotation. As the 16-APSK OFDM system using the APS-pilot method is highly effective, this is shown through the results in figure 6 and figure 7.

The automatic compensation of the phase rotation angle taken from the pilot will always be compensated and optimal for the system, even if the system parameters change. In fact, this method can be easily implemented at the receiver by inserting pilots when training the system and inserting them periodically according to a given time.

The group's future research direction is to consider using APS-pilot method to reduce the simultaneous effects of linear distortion and nonlinear distortion for a specific system.

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TÓM TẮT

Giảm tác động của méo phi tuyến trong hệ thống 16-APSK OFDM bằng quay pha tự động dựa trên pilot

Bài báo đề xuất phương pháp giảm ảnh hưởng của méo phi tuyến trong hệ thống 16-APSK OFDM, đó là phương pháp quay pha tự động dựa trên pilot. Pilot phát được chèn vào trong quá trình điều chế OFDM ở máy phát. Khi pilot đi qua bộ KĐCS của hệ thống, nó sẽ mang thông tin đầy đủ về độ méo phi tuyến của bộ KĐCS. Ở máy thu, góc pha được quay tự động dựa trên độ lệch pha giữa pilot thu và pilot phát mà không phụ thuộc vào bộ khuếch đại công suất hay thông số của hệ thống. Khi sử dụng phương pháp APS-pilot trong hệ thống OFDM, hiệu năng giảm méo phi tuyến của nó gần giống với phương pháp OAPS, mà không cần tính toán công thức thực nghiệm OAPS, cũng như cài đặt trước OAPS theo cách thủ công tại máy thu.

Từ khoá: OFDM; Méo phi tuyến; HPA; APS-pilot.