International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 5 ǁ May 2024 ǁ PP. 66-72

Reduce effect of the nonlinear distortion in 16-APSK OFDM system by OAPS method

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Abstract
Nonlinear distortion caused by HPA (High Power Amplifier) in 16-APSK OFDM systems is very severe. So there are a lot of countermeasures nonlinear distortion in both of the transmitter and the receiver. One of measures that can be done quite simply in the receiver is to use OAPS method (Optimum Additional Phase Shift). In this paper, by using computer simulation a OFDM system is considered and empirical formulae between OAPS and dd (distance degradation) are found. These results can calculate quickly and simply the OAPS to reduce the effect of non-linear distortion caused to this proposed system.
Keywords: *OFDM, nonlinear distortion, HPA, OAPS*

Date of Submission: 28-04-2024 Date of acceptance: 07-05-2024

I. 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 DVB-S2 satellite digital television, the mobile radio networks 4G, 5G .… However, OFDM systems sensitive to nonlinear distortion caused by HPAs, lead to the sharp decline in system quality. That is causing nonlinear ISI, wrapping the constellation, causes nonlinear noise (inband) and expand the output signal bandwith. Therefore, countermeasures nonlinear distortion caused by HPA has been and is being studied by a lot of scientists.

Countermeasures nonlinear distortion in the transmitter include: using BO (back-off) optimal [1]; using Pre-Distorter [2]; reduce PAPR with OFDM systems [3],…. 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 this studies, the authors used the OAPS method because it can be performed at the receiver, with relatively high efficiency [4-6].

The paper is organized as follows: The introduction is given in Section 1; Section 2 is OAPS method; System model and dd parameter are presented in Section 3; Result and discussion are given in Section 4; Section 5 is used for the conclusion.

II. OAPS METHOD

Optimum Additional Phase Shift method for *M*-QAM digital microwave systems was proposed and calculated by N. Q. Binh [4]. The OAPS method diagram is shown in Figure 1, the signal of receiver carrier from the output of a phase-locked loop go through a additional phase shift circuit before sending to demodulation circuit.

Under the influence of this secondary additional phase rotation, the spatial coordinate system of the received signal is rotated at an angle equal to the APS, the decision boundaries rotate and therefore the distance from the signal points to the nearest decision boundary will increase, the bit error rate will decrease.

It can be seen that the APS additional phase rotation angle cannot be increased forever, because as the APS increases, the distance from the signal points to this decision edge increases, the distance to the other decision edge decreases. Therefore, there exists an optimal APS value, called the optimal auxiliary phase rotation angle OAPS.

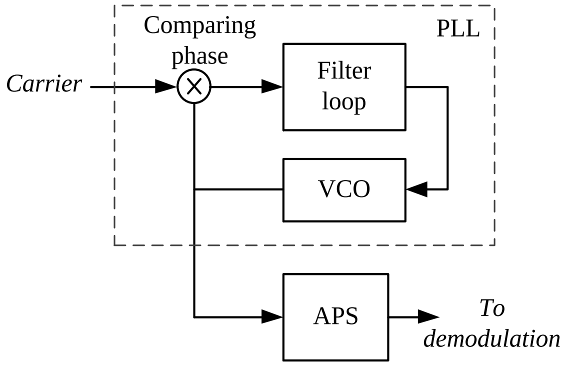

Figure 1: Additional phase shift diagram

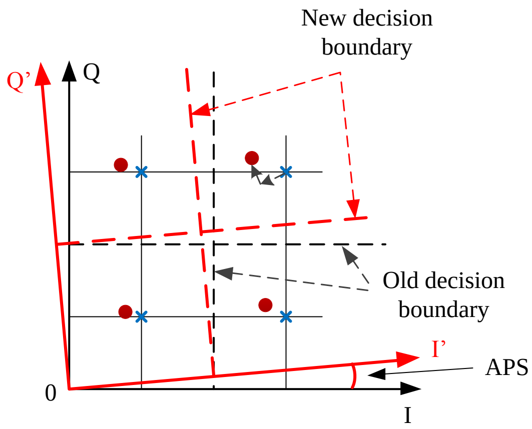

Figure 2: Receiver carrier additional phase rotation

III. SYSTEM MODEL AND *DD* PARAMETER

3.1 System model

The OFDM system under consideration is modeled in Fig. 3.

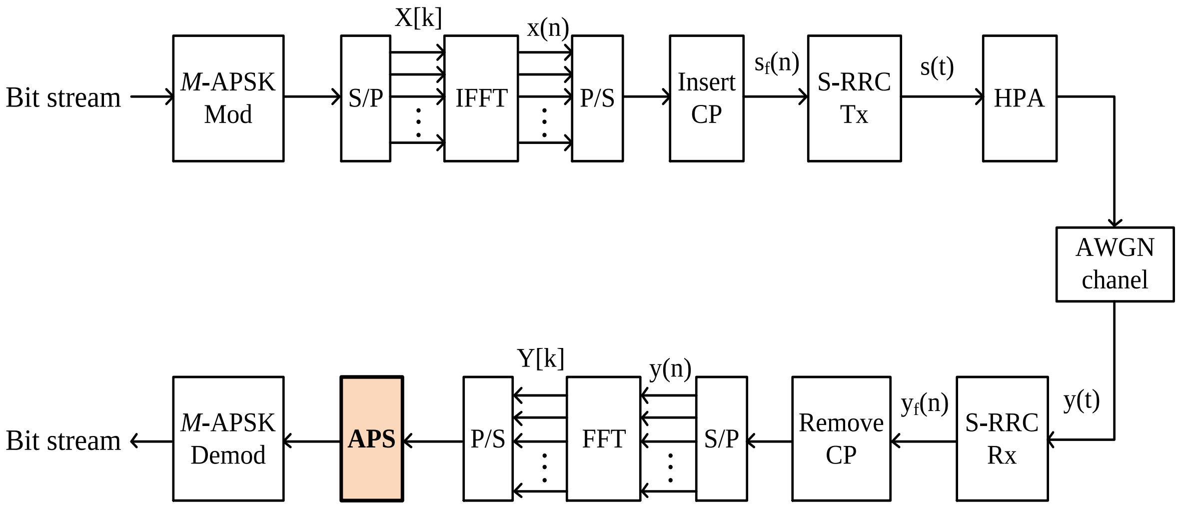

Figure 3: Surveying model of OFDM system

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 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 APS block as shown in Fig. 3.

3.2 Power amplifier models

HPA is modeled as a nonlinear element, described by the curve AM/AM and AM/PM [7]. According to this model, if performed input signal symbol according to polar coordinates are:

$$s = re^{j\theta}; \ \hat{s} = A(r)e^{j\varphi(r)}e^{j\theta}, \tag{1}$$

for r and θ are the amplitude and the entrance signal phase respectively; $\hat{s}$ is the exit symbol HPA; $A(r)$ and $\varphi(r)$ are the AM/AM and AM/PM modulation which are determined according to Saleh [7]:

$$A(r) = \frac{\alpha_a r}{1+\beta_a r^2}; \ \varphi(r) = \frac{\alpha_p r^2}{1+\beta_p r^2}, \tag{2}$$

where α_a, β_a and α_p, β_p are the parameters of Saleh model. This parameter of 3 HPA are selected unintentionally from several research before and are listed in Table 1 [4, 7].

Table 1 The parameter of HPA according to Saleh model

Name of HPA and parameter	HPA267	HPA1371	HPA1373
α_a	2	1.9638	2.1587
β_a	1	0.9945	1.1517
α_p	$\pi/3$	2.5293	4.0033
β_p	1	2.8168	9.1040

3.3 *dd* parameter

Distance degradation (*dd*) is the degradation of the distance from the signal states to the nearest decision boundary averaging on all of signal set [4]. With any HPA and a Peak Back-off (BO_P), *dd* can easy to be determined by the following formula:

$$dd = \frac{4}{M}\sum_{i,j=1}^{\sqrt{M}/2} dd_{i,j} \tag{3}$$

where $d_{i,j}$ is the minimum distance from the signal point to the nearest boder. The distance damage for signal $[i,j]$ là $dd_{i,j} = 1 - d_{i,j}$. For each HPA, the characteristic of declining gain ΔG and phase distortion $\Delta\Phi$ at the output as a function of the output power and is given by producer. From these characteristics and the given BO_P (The ΔG_{ij} and $\Delta\Phi_{ij}$ are identified for every signal point $[i, j]$), By using geometry, we can easy to identify the values d_{ij}, and $i, j = 1, 2,\ldots, \sqrt{M}/2$ as shown in Fig. 4.

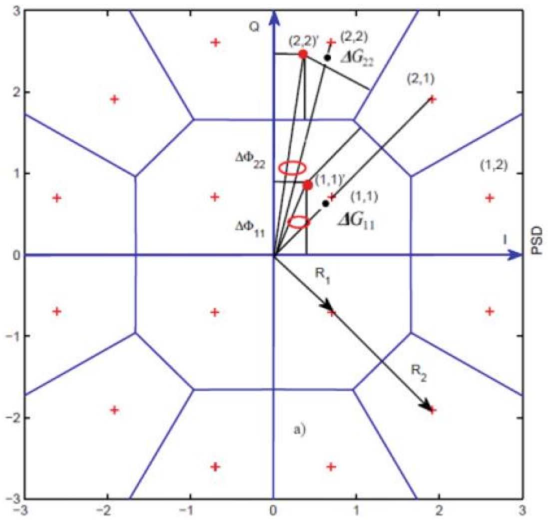

Figure 4: How to determine dd in 16-APSK signal constellation

IV. RESULT AND DISCUSSION

We simulated using Matlab software very long times to determine the OAPS angle. The 16-APSK OFDM system model used for simulation is shown in Fig. 3. The parameters used in the 16-APSK OFDM system simulation are:

- Number of simulation bits: the number of random bits is 128 000 000 (a sequence of 2 000 000 consecutive OFDM symbols, each OFDM symbol consists of 64 bits is modulated in parallel on 16 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 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).

- We investigated only the effect of nonlinear distortion, so the channel is AWGN.

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

We simulate using Matlab about 600 times, each time about 4 hours for a computer with core i5 configuration. There are 3 HPAs, each HPA runs about 10 BO values, each BO value runs an average of 20 times corresponding to APS values.

In the 16-APSK OFDM system, with each HPA, at a specific BO, when changing the APS additional phase rotation angle, the BER curve of the system will change, making the SNRD value at BER = 10^{-3} and BER = 10^{-6} will change. Initially, as the APS angle increases, the SNRD value will gradually decrease. If the APS angle continues to increase, the SNRD value will decrease to a value of $SNRD_{min}$ and then gradually increase again. Thus, there will exist a $SNRD_{min}$ value and corresponding to this smallest SRND, the OAPS value will be determined.

Computer simulation using Matlab with gradually increasing APS to determine the SNRD function caused by HPA. Simulation results to find OAPS with 16-APSK OFDM system with HPA1371 and BO_m = 19 [dB] are shown in Figure 5. The OAPS value will correspond to the minimum point of the SNRD curve, in this case OAPS determines is 4.3 [degrees]. The gain provided by OAPS in this case is determined by the difference between SNRD when not in use (APS = 0) and when using OAPS (APS = OAPS) is 4.86 [dB].

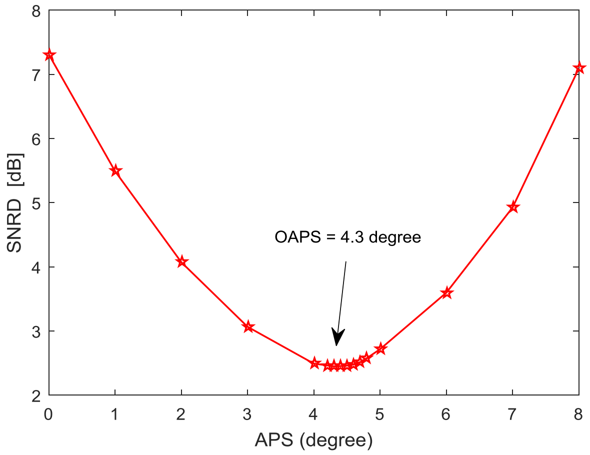

Figure 5: How to determine the OAPS angle based on the SNRD value

4.1 The relationship between OAPS and *dd*

To determine the relationship between OAPS and *dd*, we determine the OAPS angle and distance degradation *dd* corresponding to each BO_m in the useful IBO range for three HPAs, according to the algorithm flow chart in Fig. 6

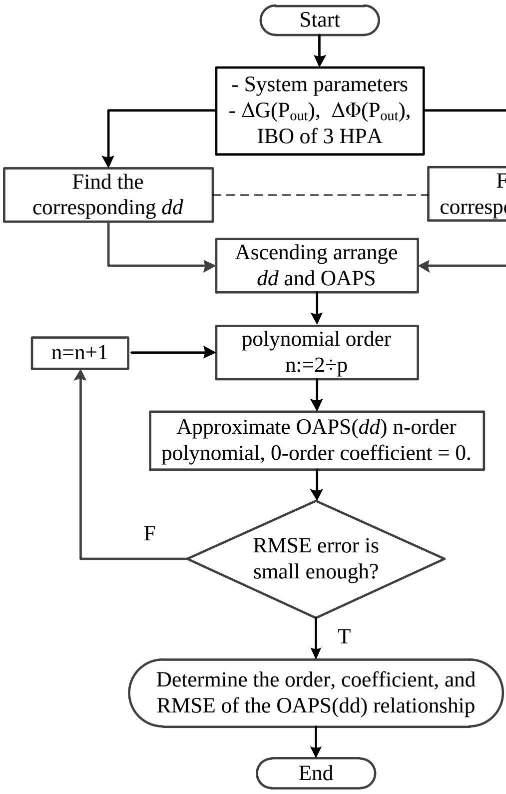

Figure 6: Flow chart of the algorithm relationship between OAPS and dd

With each HPA, in the useful IBO range, the relationship between OAPS and *dd* for 16-APSK OFDM systems can roughly approximate is a polynomial function of N order with the lowest Root Mean Square Error (RMSE). This polynomial has the term of zero order equal 0, because when HPA completely linear, the *dd* = 0 and SNRD=0 so it doesn't use OAPS. To easily calculate system design, the relationship between OAPS according to *dd* can be approximated equal a 1st-order function in the formula 3 and described in figure 7.
The empirical formula between OAPS and *dd* in 16-APSK OFDM system:

$$OAPS = a.dd \tag{3}$$

where the coefficient a is summarized in Table 2.

Table 2 coefficient a in formula (3) at BER = 10^{-3} and BER = 10^{-6}

BER=10^{-3}		BER=10^{-6}	
Coefficient *a*	RMSE	Coefficient *a*	RMSE
39.666	0.0561	40.137	0.0863

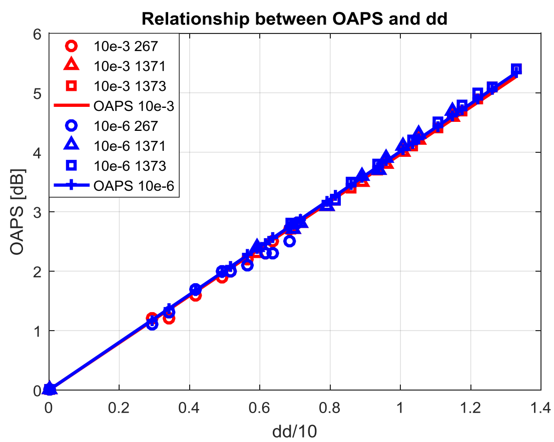

Figure 7: Relationship between OAPS and dd in 16-APSK OFDM system

From Fig. 7, we can see that: with 16-APSK OFDM system, in the case of greater *dd*, the higher the HPA's nonlinearity, thus OAPS at *BER*=10^{-3} and *BER*=10^{-3} is greater.

4.2 The relationship between SNRD and *dd*

Relationship between SNRD and *dd* when the system uses OAPS is shown in Fig. 8.

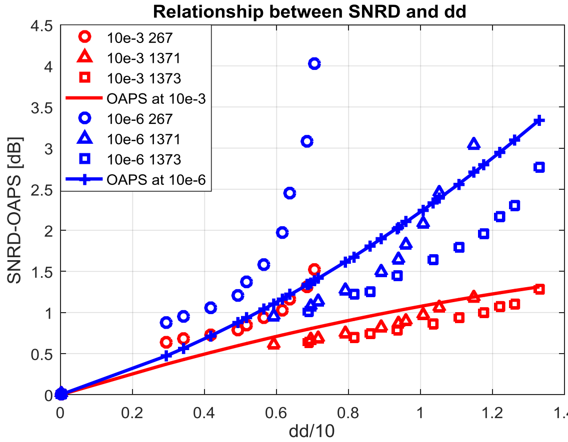

Figure 8: Relationship between SNRD and dd when the system uses OAPS

When 16-APSK OFDM system uses OAPS, empirical formula between SNRD and *dd* is:

$$SNRD = a.(dd)^2 + b.(dd) \tag{4}$$

where the coefficient *a* and *b* is summarized in Table 3.

Table 3 coefficient a and b in formula (4) at BER = 10^{-3} and BER = 10^{-6}

BER=10^{-3}			BER=10^{-6}		
Coefficient *a*	Coefficient *b*	RMSE	Coefficient *a*	Coefficient *b*	RMSE
-26.88	13.439	0.079	87.121	13.542	0.186

4.3 Gain of Optimum Additional Phase Shift

Gain of Optimum Additional Phase Shift (G_{OAPS}) is the difference between the SNRD (Signal-to-Noise Degradation) caused by the HPA's nonlinear distortion when the system uses and don't uses OAPS at a certain BER.

$$G_{OAPS} = SNRD_{APS=0} - SNRD_{APS=OAPS} \tag{5}$$

where $SNRD_{APS=OAPS}$ and $SNRD_{APS=0}$ correspond to SNRD when the system uses and don't uses OAPS.

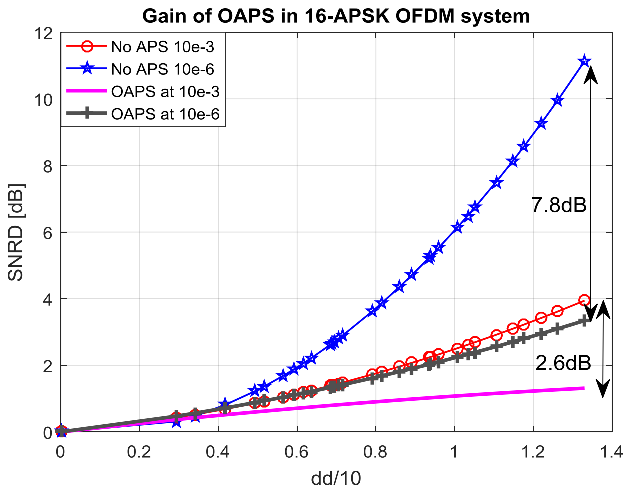

Figure 9: Relationship between SNRD and dd when the system uses and don't uses OAPS

From Fig. 9, we can see that: in the case of greater *dd*, the higher the HPA's nonlinearity, so it is more and more effective when the OFDM system is using OAPS. Detail, with *dd*= 0.133 the effectiveness of the OAPS method is $(G_{OAPS})_{max}$ = 2.6[dB] at BER=10^{-3} and $(G_{OAPS})_{max}$ = 7.8[dB] at BER=10^{-6}.

V. CONCLUSION

The obtained results and the analyses in the paper also show the effectiveness of the OAPS method in countermeasures nonlinear distortion. With very long simulation time, the paper provides an empirical formula to quickly calculate OAPS value according to *dd* and SNRD value according to *dd* at BER=10^{-3} and BER=10^{-6}. Based on this empirical formula, manufacturers will preset the OAPS value at the receiver.

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