A novel signal constellation set for communication system using APSK signals of DVB-S2 standard with high nonlinearity

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ABSTRACT

Being robust to nonlinear distortion by owning a lower peak to average power ratio in comparision with QAM signal, APSK was recommended for using in the digital satellite video broadcasting, second generation (DVB-S2). However, the adverse effects of nonlinearity could still be reduced by redistributing signal points in the constellation. In this paper, we propose a new signal set and the mapping for the APSK signal conforming to the DVB-S2 standard at high nonlinearity level. Moreover, this new proposed APSK signal further improves the performance of HPA in terms of power efficiency.

CCS Concepts

•**Computing methodologies** → Systems theory; Simulation evaluation;

Keywords

APSK; High Power Amplifier; Nonlinear Distortion; Satellite.

1. INTRODUCTION

Multilevel modulation schemes such as amplitude phase shift keying (APSK) and Quadrature Amplitude Modulation (QAM) are widely used in modern communication systems for higher bandwidth efficiency and power efficiency. A modulation scheme with lower peak-to-average power ratio (PAPR) is desired for the transmission with nonlinear distortion condition caused by high-power amplifiers (HPAs) such as travelling wave tube amplifiers (TWTA) in the satellite transponders or solid state power amplifiers (SSPAs) on handheld devices for tactical applications. With the same level of modulation, APSK has lower PAPR in comparison with that of QAM [1], it was thus proposed to implement in the digital satellite video broadcasting standard, second generation [2]. Therefore, APSK has been one of the main objects in researches improving the transmission performance over the satellite channels [3, 4, 5, 6, 7].

In [3], the authors proposed a new mapping for APSK signalling of DVB-S2 standard for performance improvement in the satellite communication system with nonlinear channel. Specifically, the idea was partially rearrange signal points in the outer ring of the 16-APSK signal set or totally redistribute all signal points in three rings of the 32-APSK of DVB-S2 standard. Again, the work [4] introduced a new mapping for the 32-APSK to ameliorate the system performance. However, the performance improvements in both proposals are insignificant.

Lately, generic algorithms (GA) were used in [5] for optimizing bit allocation of the 16- and 32-APSK mapping which gains better performance improvement compared to that of [3]. Then, a new labeling for the 32-APSK constellation with Gray code over all the ring is proposed in [6]. Most recently, Murroni and Meloni [7] conducted the GA's parameter optimization for further ameliorate of the signal set compared to what has been done in [5]. However, all these contributions neglect the amplitude modulation to phase modulation (AM/PM) distortion of HPA. Pratically, AM/PM is the main effect that could not be ignored in satellite communication systems using TWT as the HPA.

Against this background and motivated by the limitations of these above works, we suggest novel structures and mappings for 16-and 32-APSK that are more robust to the nonlinear distortion compared to the conventional APSK standardized in DVB-S2 capable working with high nonlinearity (with full amplitude-modulation to amplitude-modulation (AM/AM) and AM/PM conversions). In order to determine the effectiveness of the proposed APSK signals, The bit error rate (BER), BER gain and total degradation (TD) obtained by applying the proposed ones are compared with the results obtained by using classical APSK in DVB-S2 standard. In comparison with the conventional APSK of the standard, the proposed signal constellations have the following characteristics:

- For the 16-APSK, propose to increase number of signal points in the inner ring and reduce one phase angle in comparison with the conventional 16-APSK;
- For the 32-APSK, propose to increase to 8 signal points

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in the smallest ring, reducing 2 phase angles in comparison with the traditional 32-APSK.

We now summarize our novel contributions in this work as:

- To suggest new signal sets and mappings of 16-and 32-APSK with more robustness to nonlinearity in comparision with the APSK in the DVB-S2 standard;
- To determine the limits of the peak input power backoff (IBO_P) so that the proposed APSK gains better performance in comparision with the conventional APSK at a specific E_b/N_0;
- To identify the optimal peak input backoff for the newly proposed APSK and conventional APSK;
- At the first time to investigate the full effect of nonlinear distortion including both the AM/AM and AM/PM conversions to conventional APSK signal.

The rest of this paper is organized as follows. The system model is introduced in section 2. In section 3, we suggest the new signal 16-APSK and 32-APSK. Simulation results are presented in section 4 while our conclusions are drawn in section 5.

2. SYSTEM MODEL

Consider an APSK transmission system incuring nonlinear distortion as depicted in Figure 1. The transmitting part includes a serial-to-parallel (S/P) data conversion, an APSK modulation, a square-root raise cosine (SRRC) filter limitting the signal's bandwidth and a nonlinear HPA using TWT characterized at the Ku- or Ka-band [1]. This system represents a transponder with insignificant uplink noise in comparision with the downlink noise. The transmitted signal after Tx filter at time t is given by:

$$s_T(t) = \sum_{k=0}^{L-1} x(k)\rho_T(t - kT_s), \tag{1}$$

where $x(k)$ is the k-th transmitted symbol selected from M-APSK signal constellation, $p_T(t)$ is the impulse response of the SRRC filter and T_s is the symbol period. $s_T(t)$ is then passed through the HPA operating near the saturation point. This leads to the AM/AM and AM/PM conversions for the $s_T(t)$. The baseband complex envelope $s_T(t)$ is represented by it's amplitude and phase by $s_T(t) = |s_T(t)|\, e^{j\phi(s_T(t))}$. The HPA is modeled as a memoryless nonlinearity with the output $\tilde{s}(t)$ at time t given by:

$$\tilde{s}(t) = F(|s_T(t)|)e^{j(\phi(s_T(t))+\Phi(|s_T(t)|))}, \tag{2}$$

where $F(A)$ and $\Phi(A)$ are defined as the AM/AM and AM/PM characteristics of the amplifier for a signal with instantaneous signal amplitude A.
In [8], the AM/AM and AM/PM conversions are described as:

$$F(A) = \frac{\alpha_a A}{1 + \beta_a A^2}, \tag{3}$$

$$\Phi(A) = \frac{\alpha_p A^2}{1 + \beta_p A^2}, \tag{4}$$

where α_a, β_a and α_p, β_p are parameters of the Saleh's model determined by the minimum mean-square error (MMSE) method using data measured from real HPA. In this paper, we use HPA with $\alpha_a = 2$, $\beta_a = 1$, $\alpha_p = \pi/3$ and $\beta_p = 1$ for simulating and evaluating the performance of the proposed APSK. The AM/AM and AM/PM conversions of the investigated HPA are characterized in Figure 2a.

After passing through HPA, the amplified signal is transmitted over channel that is only affected by the additive white Gaussian noise (AWGN) with zero mean and variance of $N_0/2$.

At the receiving part, the received signal is pass through the matched filter and then demodulated and decided by maximum likelihood criterion (ML).

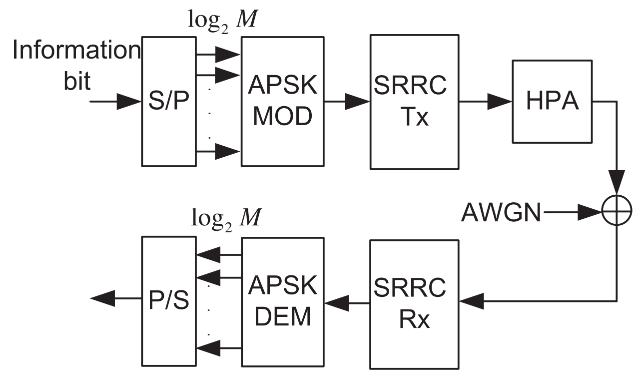

Figure 1: System model.

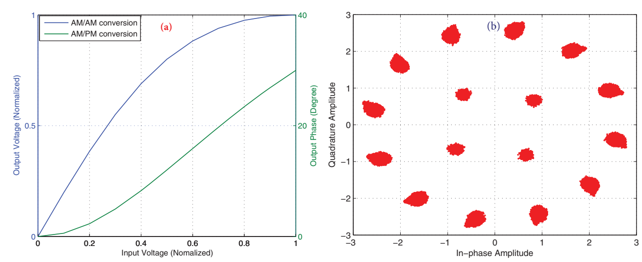

Figure 2: a). AM/AM and AM/PM conversion characteristics; b). The 16-APSK conformed to the DVB-S2 standard after being passed through the HPA.

3. PROPOSAL OF NEW STRUCTURES AND MAPPINGS FOR APSK SIGNALS

M-APSK signal constellation has n_R rings, where PSK signal points are regularly distributed in. These points belong to complex number set χ given by:

$$\chi = \begin{cases} r_1 e^{j(\frac{2\pi}{n_1}i+\theta_1)} & i = 0, ...n_1 - 1 \quad ring\ 1 \\ r_2 e^{j(\frac{2\pi}{n_2}i+\theta_2)} & i = 0, ...n_2 - 1 \quad ring\ 2 \\ \cdot & \\ \cdot & \\ \cdot & \\ r_{n_R} e^{j(\frac{2\pi}{n_R}i+\theta_{n_R})} & i = 0, ...n_{n_R} - 1 \quad ring\ n_R \end{cases} \tag{5}$$

where n_l, r_l and $\theta(l)$ correspondingly are number of points, radius and phase angle of the l-th ring. The DVB-S2 standard determines $\chi = 16$ and $n_R = 2$ for the 16-APSK and $\chi = 32$ and $n_R = 3$ for the 32-APSK as depicted in Figure 3 and Figure 4.

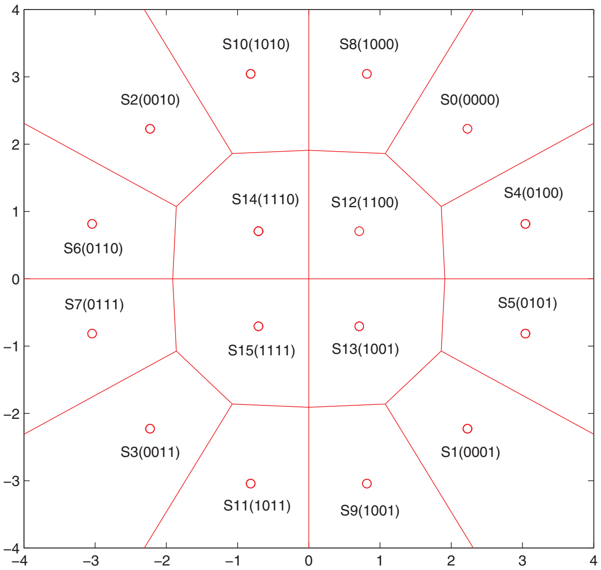

Figure 3: The conventional 16-APSK as defined in the DVB-S2 standard.

It is observed in Figure 2a that signal points with smaller magnitudes are less affected by nonlinear distortion compared with ones in the larger ring. Further more, the effect of AM/PM conversion should be more significant than that of AM/AM conversion. This observation is illustrated by the distribution of signal sets in Figure 2b. This is the very effect of AM/PM conversion that dramatically broadens the signal points with larger magnitudes.

Besides, by the symmetry of the constellation, if only considering the first quadrant for the conventional 16-APSK signal set, there are three phase angles of $\pi/12$; $\pi/4$ and $5\pi/12$, while for the conventional 32-APSK signal set, there are seven phase angles of 0; $\pi/12$; $\pi/8$; $\pi/4$; $5\pi/12$; $3\pi/8$ and $\pi/2$. On the other hand, among AM/AM and AM/PM conversion effects caused by HPA constructed from TWT, this is very AM/PM that plays the main role degradating the system's performance. Therefore, it would be better if these constellations are rearranged so that as much as possible signal points in outer ring(s) are reallocated into the inner one(s) and as smallest as possible phase angles are introduced. This discipline would result in signal constellations that are more robust to the adverse AM/PM effects caused by non-linear HPA. However, these contellations might be worse than the conventional ones when comparing in linear conditions or in weak nonlinearity of AM/PM conversion or in AM/AM distortion only. It is emphazized again that this design is only effective in systems that have large nonlinearity of AM/PM conversion. Based on these arguments we propose novel 16- and 32-APSK signal set replacing the APSK schemes in the DVB-S2 standard that should outperform in large nonlinearity as follows.

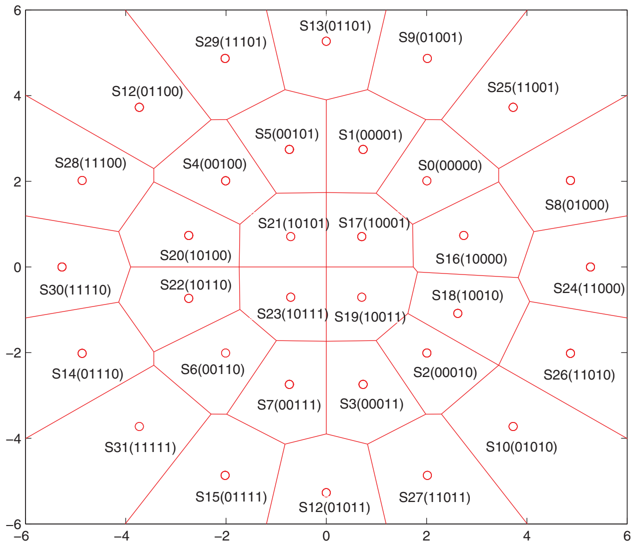

Figure 4: The conventional 32-APSK as defined in the DVB-S2 standard.

3.1 Proposal of novel 16-APSK

Following principles described above, there are several solutions to redistribute signal points in outer ring into the inner one and to posit to reduce the phase angles of the new signal set. However, thorough consideration results in the optimal signal constellation as depicted in Figure 5. The drawing of four points from the outer ring into the inner one results in the benefit of capable using Gray mapping for the newly formed constellation which has the property of equally distributing signal points into the two rings. Besides, the number of phase angles reduces one in comparison with that of the conventional 16-APSK, remaining two phase angles of $\pi/8$ and $3\pi/8$ in the first quadrant.

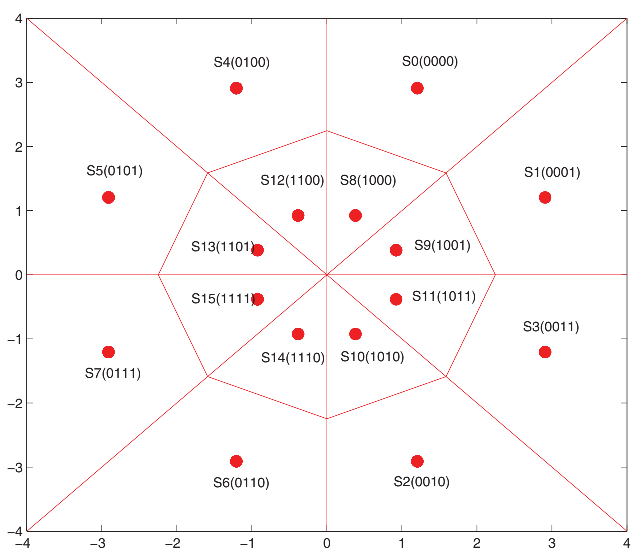

Figure 5: The proposed signal constellation and its mapping for 16-APSK.

As observed in Figure 5, the proposed 16-APSK has the following advantages in comparison with the conventional one:

- Signal points of larger magnitudes reduce by four and ones of smaller magnitude increase by four so that the effects of nonlinear HPA with large AM/PM conversion are lessened;
- While the conventional 16-APSK could only be used with quasi-Gray mapping, the proposed signal constellation could be combined with a Gray mapping so that better performance could be gained.

3.2 Proposal of novel 32-APSK

As same as the proposed 16-APSK, we draw four signal points in the most outering into the most inner one to reduce the nonlinear distortion effect. With none-radial distribution of the newly formed constellation, it is impossible to use Gray mapping. Therefore, we suggest the structure and the bit mapping for the 32-APSK as illustrated in Figure 6.

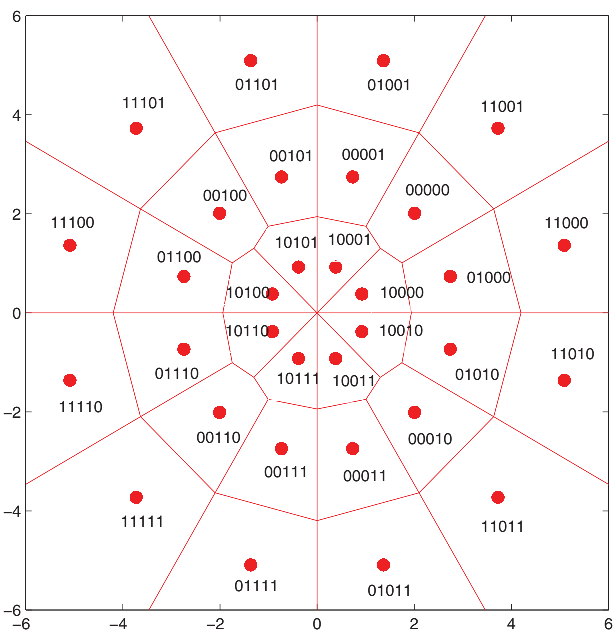

Figure 6: The proposed signal constellation and its mapping for the 32-APSK.

4. SIMULATION RESULTS AND ANALYSIS

For the performance evaluation of the proposed APSK in comparison with the conventional one conforming to the DVB-S2 standard, we carried out by simulating with the same system configuration as described in Figure 1, the 16-APSK has the same radius ratio of $\gamma = 3.15$, as defined in the DVB-S2 standard, while the proposed 32-APSK has the same second ring-to-first ring radius ratio of $\gamma_1 = 2.84$ and third-to-first ring radius ratio of $\gamma_2 = 5.27$.
Other system's parameters such as SRRC filters at transmitting and receiving parts have the same: rolloff factor $\alpha = 0.5$, input sampling rate $F_d = 1$, output sampling rate $F_s = 8$; the HPA in the form of TWT is described by and has the Saleh's parameters as in Section 2, the investigating parameter is the peak input power backoff IBO_P given by:

$$IBO_P = 10\log_{10}\frac{P_{sat}}{P_{peak}}, \tag{6}$$

where P_{sat} and P_{peak} are correspondingly the saturation power and the peak power of the input HPA signal. Simulating results for the proposed and conventional APSK are in the forms of bit error ratio (BER), BER gain at a specific E_b/N_0 and the total degradation by IBO_P

4.1 The bit error rate

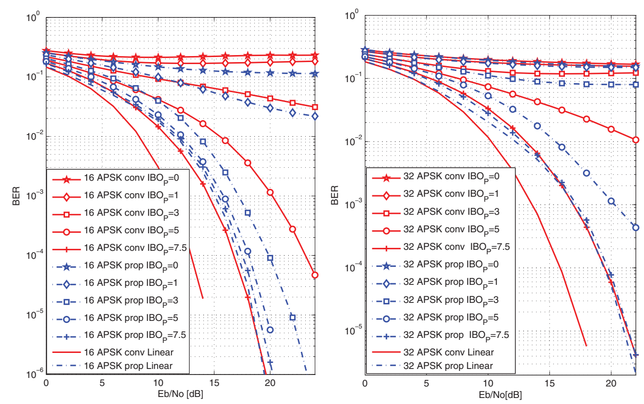

Figure 7: Simulated BER performance of the proposed APSK and the conventional APSK in linear and nonlinear conditions.

It is easy to see that in the case without the effects of HPA (system operating in linear condition) the performance of the proposed APSK system is worse than that of the conventional APSK system. This is accounted for more signal points in the inner rings of the proposed APSK systems (8 points in 16-APSK and 20 points in 32-APSK). This is the more closeness of these signal points that are more vulnerable to errors. Although, there are less signal points in the outer ring(s) of the proposed APSK system (8 points in 16-APSK and 12 points in 32-APSK) compared with the counterparts of the conventional systems (12 points in 16-APSK and 16 points in 32-APSK). The performance improvement by these points in the proposed systems can not compensate for the degradation caused by the more close remaining points in the inner ring(s) as analysed above. Therefore, the conventional systems outperform the proposed system in linear operating environment.

When operating in nonlinear condition, at IBO_P upto 5 [dB] the proposed APSK systems always surpass the conventional counterpart in terms of BER performance. The reason for this is as follows. The HPA results in AM/AM and AM/PM conversion effects (with the later dominates), while with the smaller numbers of phase angles and larger numbers of signal points in the inner rings, the proposed systems are less subjected to the AM/AM conversion effects compared with what happening in the conventional systems. Consequently, the proposed APSK systems are more robust than the conventional counterparts especially at smaller IBO_P.

It is also observed from Figure 7 that three exists a benchmark value for IBO_P that separates the robustness of the proposed systems to the nonlinear distortion. If the HPA operates at larger IBO_P than this benchmark value, the BER performance of the proposed systems will be inferior to that of the conventional counterparts. This problem will be detailed in the following next section.

4.2 BER gain of the proposed APSK compared to the conventional one

To evaluate the performance of the proposed APSK, we introduce a parameter G, the bit error rate gain at specific Eb/N_0 for system using the proposed APSK compared to that of system with the conventional APSK, defined as:

$$G = BER_{APSK_{conv}} - BER_{APSK_{prop}}, \tag{7}$$

where $BER_{APSK_{conv}}$, $BER_{APSK_{prop}}$ correspondingly are the BER of system using conventional APSK and the BER of system using the proposed APSK at a given Eb/N_0. It is not difficult to see that, if $G \geq 0$ then the system with proposed APSK outperforms the counterpart with the conventional APSK and vice versa. Figure 8, reveals that at $IBO_P = 1$ [dB], the gain reaches its peak for 16-APSK case, $G_{16-APSK} = 0.1461$. On the other hand, $G_{32-APSK} = 0.0486$ is the maximum gain for the 32-APSK case at $IBO_P = 3.5$ [dB]. Besides, when $IBO_P \geq 7.24$ then $G_{16-APSK} \leq 0$ namely, the proposed 16-APSK is inferior to the conventional one. For the 32-APSK case, the performance of the conventional 32-APSK system is superior to that of the proposed 32-APSK when $IBO_P \geq 7.44$ [dB].

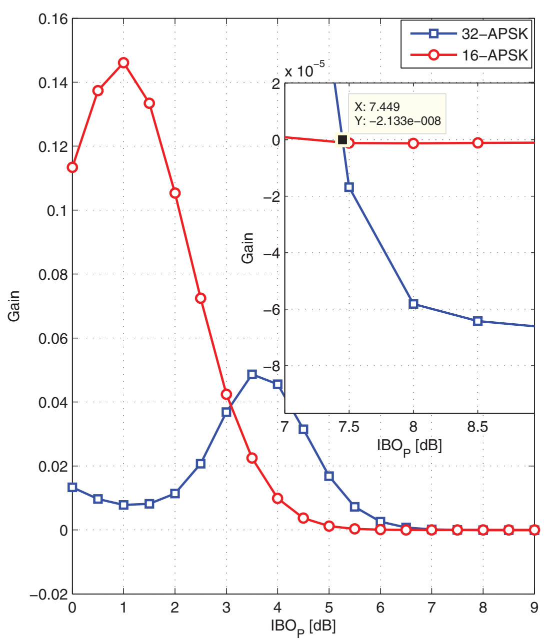

Figure 8: The BER gain of the proposed APSK compared to the conventional APSK at $Eb/N_0 = 20$ [dB].

4.3 The system total degradation by IBO_P

At this section, we will investigate the performance of the proposed system compared to that of the conventional counterpart at BER $= 10^{-3}$ in terms of the total degradation, which are a common figure used in determining the performance of satellite communication systems under nonlinear distortion condition [10]. By [1], [9] and [10], TD is defined by IBO_P as:

$$TD[dB] = Eb/N_0^{NL}[dB] - Eb/N_0^{L}[dB] + IBO_P, \tag{8}$$

where Eb/N_0^{NL} and Eb/N_0^{L} are the average Eb/N_0 at the receiving site correspondingly to the case with and without the effects of HPA. By thoroughly simulating the system with different values of IBO_P, the relationships of TD and IBO_P at BER $= 10^{-3}$ are sketched out in Figure 9.

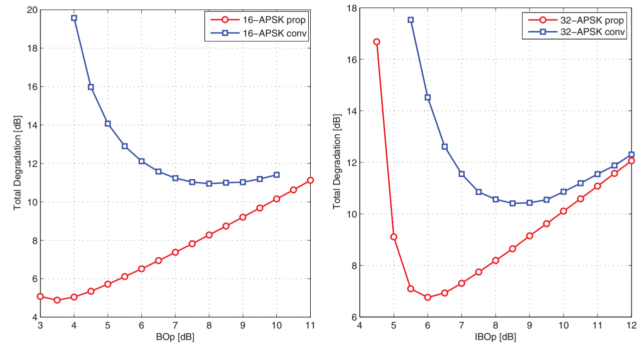

Figure 9: Total degradation (TD) versus peak input backoff power (IBO_P) at BER $= 10^{-3}$ of the proposed system and the conventional one.

The results in this figure show that the optimal operating points of HPA in system using the proposed 16-APSK are dramatically reduced particularly, from $IBO_{opt} = 8$ [dB] decreasing to $IBO_{opt} = 3.5$ [dB] and for the 32-APSK case, the optimal IBO_{opt} of HPA reducing from $IBO_{opt} = 8.5$ [dB] to $IBO_{opt} = 6$ [dB]. At a result the effectiveness of HPA interm of power efficency is greatly improved when using the proposed APSK in system investigated.

5. CONCLUSIONS

In this work, we has proposed novel structures and their mappings for 16-APSK and 32-APSK schemes that are more robust to nonlinear distortion in comparison with the conventional APSK signal of the DVB-S2 standard in highly nonlinear working condition. Particularly, the novel structure is capable to combine with the Gray encoding so that the robustness to nonlinear distortion is significantly improved in compared to the conventional 16-APSK. Besides, this newly proposed APSK still greatly improved the effectiveness of HPA in term of power efficiency.

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