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Compensation of the Nonlinear Power Amplifier by Using SCPWL Predistorter with Genetic Algorithm in OFDM technique

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ABSTRACT

The High Power Amplifiers (HPAs), which are used in wireless communication, are distinctly characterized by nonlinear properties. The linearity of the HPA can be accomplished by retreating an HPA to put it in a linear region on account of power performance loss. Meanwhile the Orthogonal Frequency Division Multiplex signal is very rough. Therefore, it will be required a large undo to the linear action area that leads to a vital loss in power efficiency. Thereby, back-off is not a positive solution. A Simplicial Canonical Piecewise-Linear (SCPWL) model based digital predistorters are widely employed to compensating the nonlinear distortion that introduced by a HPA component in OFDM technology. In this paper, the genetic algorithm has been used to optimized the SCPWL coefficients by using Matlab 2015b, and then the Bit Error Rate (BER) performance has been evaluated for OFDM signal with 16-QAM and 64-QAM modulations in three cases, with nonlinear effects, without nonlinear effects (ideal case), with SCPWL and with nonlinear effects (compensated case)). The simulation results showed that the predistorter that adjusted by the genetic algorithm accomplishes huge execution change by successfully compensating the nonlinearity and reducing the input and output back-off (IBO, OBO) of the HPA.

Keywords: nonlinear power amplifier, genetic algorithm digital predistorter, simplicial canonical piecewise linear model.

تعويض التشويه غير الخطي لمضخم القدرة العالية في أنظمة OFDM باستخدام المعوض SCPWL مع الخوارزمية الجينية

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الخلاصة

مضخمات القدرة العالية المطبقة في الاتصالات اللاسلكية تسلك بوضوح خصائص غير خطية. ويمكن تحقيق خطيته عن طريق تقليل اشارة الدخل إلى منطقته الخطية على حساب فقدان كفاءة في القدرة. وبما ان مقدار تغير آشارة الـ OFDM كبير. لذلك، سوف تكون هناك حاجة إلى تراجع كبير للوصول الى منطقة العمل الخطية ليؤدي إلى خسارة كبيرة في كفاءة المضخم. وبالتالي، وهذا ليس حل ايجابي. ويستخدم على نطاق واسع نموذج SCPWL كمعوض مسبق رقمي لتعويض التشويه غير الخطي التي التي سببتها المكبرات في أنظمة الـ OFDM. في هذا البحث، الخوارزمية الجينية استخدمت لحساب افضل قيم لمعاملات الـ SCPWL باستخدام الماتلاب 2015b وتم تقييم أداء الـ BER لاشارة الـ OFDM مع تضمينين 16-QAM و 64-QAM في ثلاث حالات: وجود التشويه، وعدم وجود التشويه و وجود المعوض والتشويه في آن واحد، وأظهرت نتائج المحاكاة أن SCPWL مع الخوارزمية الجينية ينجح بتعويض التشويه غير الخطية التي أدخلتها مكبرات القدرة وتقليل من التراجع الى المنطقة العمل الخطية.

الكلمات الرئيسية: مضخمات القدرة العالية، الخوارزمية الجينية، تعويض رقمي مسبق لتعويض التشوهات غير الخطية.

1. INTRODUCTION

The growing request for high data rate because of the explosive growth of new multi-media wireless applications have brought about an expanded interest for advancements that support fast transmission rates, portability and proficiently utilizing the available spectrum and system resources. An OFDM is one of the best technique that contributed for accomplishing this objective and it offers a promising decision for future fast information rate systems, **Cimini, 1985, and Bingham, 1990.** In OFDM modulation scheme different information bits are adjusted at the same time by multiple carriers. The main motivation to utilize the OFDM system is to improve robustness against the frequency selective fading channel **, Bhoge, 2017.** Nonetheless, in the radio systems, the distortion presented by HPA, for example Traveling Wave Tube Amplifier (TWTA) considered in this paper. Since the signal amplitude of the OFDM system is Rayleigh-disseminated, the performance of the OFDM system is fundamentally degraded by the nonlinearity of the HPA in the OFDM transmitter. In the literature, different modern linearization procedures for OFDM have been proposed, the digital predistortion has got a maximum acquisition of attention. Lately, many predistortion methods for OFDM have been proposed such as: **Sergey**, **2016,** have been proposed an algorithm for joint channel response and PA model estimation for OFDM signals. **Solovyeva and Kondakov 2015,** are used the decomposed piecewise memory polynomial as a Digital predistorter compensation (DPD) Model to compensate the in the nonlinear distortion. **Maryam, et al., 2014,** presents an adaptive digital pre-distortion techniques based on Look up Table (LUT) approach which will result in abandonment of nonlinear distortion producing from power amplifier. **Tushar, et al., 2013,** investigates the study of nonlinear distortion effects in an OFDM system when the signal is passed through a nonlinear HPA. **Hernandez, et al.**, **2012,** used many of the adaptive algorithms based on the mean square error criteria are used to optimize the coefficients in the Volterra Series for reducing the nonlinear distortion of the memory PA. **Sharma, 2011,** propose Selected Mapping (SLM) with predistortion technique to decrease the nonlinear distortion and to improve the power efficiency of the HPA. **Yitao, 2010,** have been presenting a novel predistorter design using a set of orthogonal polynomials to increase the convergence speed and compensation quality. **Seo, et al., 2010,** has also been proposed a SCPWL models based on DPD to compensate for nonlinear distortion introduced by a HPA in OFDM systems. **Werner, et al., 2008,** Power Amplifier (PA) Nonlinearity Cancellation (PANC) technique was proposed that reduces the harmful effects of broadband PAs in OFDM systems. In this paper, the SCPWL model has been optimized by the genetic algorithm to compensate the nonlinear distortion presented by a HPA in an OFDM system. The OFDM system affected by Additive White Gaussian Noise channel (AWGN) with two type of modulation schemes 16-QAM and 64-QAM and 64 -point FFT/IFFT has been simulated using Matlab. The simulation results show that the

SCPWL predistorter accomplishes significant performance change by successfully making up for the nonlinearity presented by the HPA.

2. SYSTEM MODEL

In a wireless transmission scheme, when it is ought to utilize a HPA to get transmit power margin, the power efficiency of the system is decreasing because of its nonlinear distortion effect. In this section, the properties of the HPA, SCPWL model and Genetic algorithm, which is adopted in this paper, are described.

2.1 Power Amplifier Model

A broadly employed memoryless nonlinear PA model in the literature is the Saleh model. The polar representation of the Saleh model is given by Eq. (1) and Eq. (2), **O'Droma, 2009**.

$$A(r) = \frac{\alpha_a\, r}{1 + \beta_a\, r^2} \qquad (1)$$

$$\Phi(r) = \frac{\alpha_\theta r^2}{1 + \beta_\theta r^2} \qquad (2)$$

where r is the absolute input signal to the nonlinear power amplifier, A(r) is the amplitude distortion function due to HPA, Φ(r) is the phase distortion function due to HPA, α_a, α_θ, β_a and β_θ are gain factors.

2.2. Simplicial Canonical Piecewise-Linear (SCPWL) Model

A Piecewise Linear (PWL) function is utilized to allotments the input vector into a predetermined number of pieces, every one depicted by a linear affine function. Conventional PWL functions are expressed region by region and in this manner require a gigantic measure of coefficients. A reduced frame is identified as the canonical PWL function. It is displayed as a worldwide function with a great deal fewer coefficients than the normal PWL function. Afterward, the idea of simplicial divider is utilized as a part of paper, **Julian, et al., 1999,** to create PWL works in a much more reduced shape. This class of PWL function identified as an (SCPWL) function. The general expression of this function has given by Eq. (3)**, Seo, et al., 2010**.

$$y(k) = c_0 + \sum_{i=1}^{\sigma-1} ci\, \lambda i(k) \qquad (3)$$

Where λ_i is the *i*-th basis function and ci are the coefficients of the SCPWL function. The equation of the basis function is specified by Eq. (4)**, Seo, et al., 2010**.

$$\lambda_i(k) = \begin{cases} \frac{1}{2}(x(k) - \beta_i + |x(k) - \beta_i|) & x(k) \le \beta_i \\ \\ \frac{1}{2}(\beta_\sigma - \beta_i + |\beta_\sigma - \beta_i|) & x(k) > \beta_\sigma \end{cases} \qquad (4)$$

Where β_i is the *i*-th predefined partition point. The parameters β_i divide the domain in equal partitions. The block diagram configuration of the SCPWL model for this study is presented in **Fig. 1**.

2.3. Genetic Algorithm

When there is an urgent need to find something specific within a vast array of possibilities, the appropriate tool will be the optimization techniques. One of the most powerful algorithms has been designed to solve this problem is the genetic algorithm. This algorithm will be used to improve the power amplifier performance by adjacent the coefficients of the SCPWL model. The main steps of this algorithm are shown in **Fig. 2**. In this paper, the fitness function that used to adjacent the coefficients of SCPWL model is given by Eq. (5). The complete system model structure is shown in **Fig. 3** and the summarized in Table 1.

$$Fitness\ function = \text{mean}(|desired\ signal - Output\ signal|) \qquad (5)$$

Where the $desired\ signal$ is the predistorter input and $Output\ signal$ is the HPA output.

3. RESULTS

The most major parameters, which it used in this simulation, are specified in the Table 2. When the best value of the fitness function was calculated within 10 generations, the ci and βi coefficients, as a result of the genetic algorithm, were compensated in the SCPWL model for evaluation. As in Fig. 4.

The constellation points of the 16-QAM modulation scheme is given in **Fig. 5** and **Fig. 6**. The blue dots and the red dots represent the digital symbols transmitted through a nonlinear HPA without compensation as shown in **Fig. 5**, and the symbols transmitted through the HPA followed by DPD respectively as shown in **Fig. 6**.

The **Fig. 7** demonstrates comparisons of the nonlinear characteristics for the cases of the HPA with no predistortion, with the predistorter, and the predistorter response. As appeared in the figure the Input Back-Off (IBO) and Output Back-Off (OBO) of the amplitude signal after the compensation are 0.294 and 0.585 respectively, while the Input Back-Off (IBO) and Output Back-Off (OBO) of the amplitude signal after the compensation are 0.156 and 0.162 respectively.

The performance of the system is also being tested based on the BER vs. SNR with range from 0 dB to 20 dB. In **Fig. 8** and **Fig. 9**, the system performance in term of the BER has been computed with two modulations 16-QAM and 64-QAM. The performance of the grouping of the predistorter and HPA is matching near to the ideal case. From the two figures, when the modulation level is increased, the nonlinearity is also increased that leading to depredate the overall performance of the system.

4. CONCLUSION

In this research, we have tested evaluation of a predistorter depending on the SCPWL model to compensate the nonlinear distortion which it is introduced by HPA with aiding of the genetic algorithm. The execution of the predistortion scheme for OFDM signal is assessed in terms of BER. Matlab simulation shows that the predistorter accomplishes huge decrease to the nonlinearity of a HPA by adjusting the SCPWL parameters using the genetic algorithm over less than 10 generations. The IBO and OBO has changed from (0.294 & 0.585) to (0.156 & 0.162) respectively.

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NOMENCLATUR

A(r) = the AM/AM function
ci = the real-valued coefficients of the SCPWL function.
$f(x)$ = SCPWL function
r = input signal
Φ(r) = the AM/PM function
α_a = amplitude gain factors
α_θ = phase gain factors
β_a = amplitude phase compression factor
β_θ = phase compression factor
λ_i = i-th basis function
β_i = the i-th predefined partition point

Table 1. Summarized of the complete system**.**

Main steps
Generation for OFDM signal
Initialization of the [c1 c2 c3 β1 β2 β3]
Applied the predistorter on the OFDM signal as in Eq. 4 and Eq. 3
Applied the nonlinear power amplifier as in Eq. 1 and Eq. 2
Compute the Fitness function as in Eq. 5
If the Fitness function <0.005, the generation will stop.
Else, Reproduction, Crossover, Mutation and New generation.
Back to the step 5.
Add the output signal of the HPA to the AWGN
Demodulation for the OFDM signal

Table 2. Simulation parameters.

Parameter	**Disruption**
Modulation Techniques	16-QAM and 64-QAM
Normalized factor modulation	$0.34\times\sqrt{10}$ and $0.34\times\sqrt{42}$
# of samples/bit	1
AWGN Channel	Yes
SNR range	[0 to 20]
Bit rate	10 Mb/s

FFT/IFFT	64
Optimum coefficients of the SCPWL Model	ci=[0.52 0.11 0.232]
c_o	0
Optimum predefined partition point	βi=[0 0.351 0.61]
β_a	0.99
α_a	1.96
α_θ	2.53
β_θ	2.82
Population size	200
Initial range	[0,1.5]
Crossover fraction	0.95
Lower limit	[0 0 0 0 0 0]
Upper limit	[1 1 1 1 1 1]
# of Generations	50

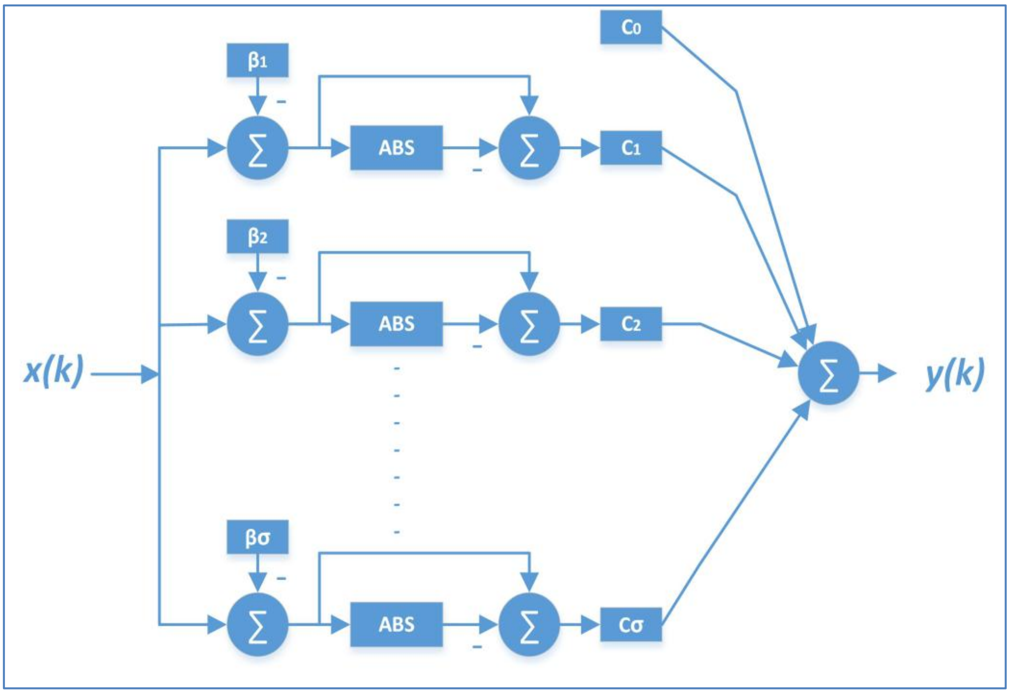

Figure 1. SCPWL structure.

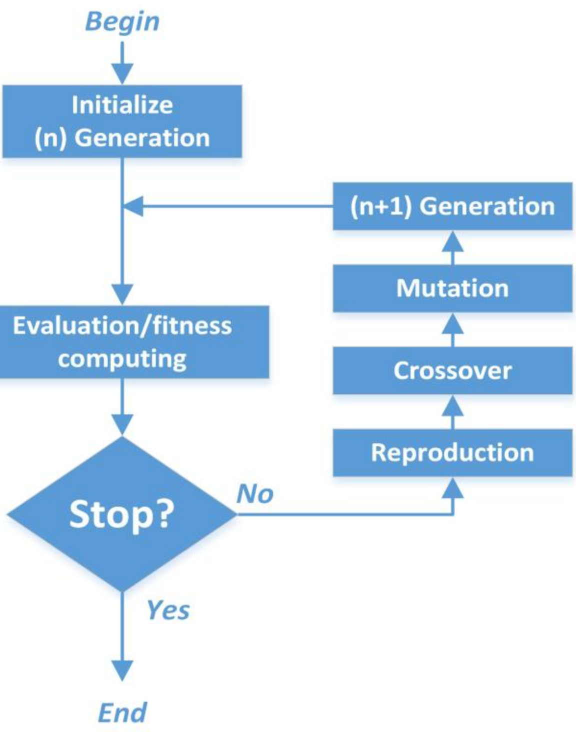

Figure 2. Flow chart of the main steps for the genetic algorithm.

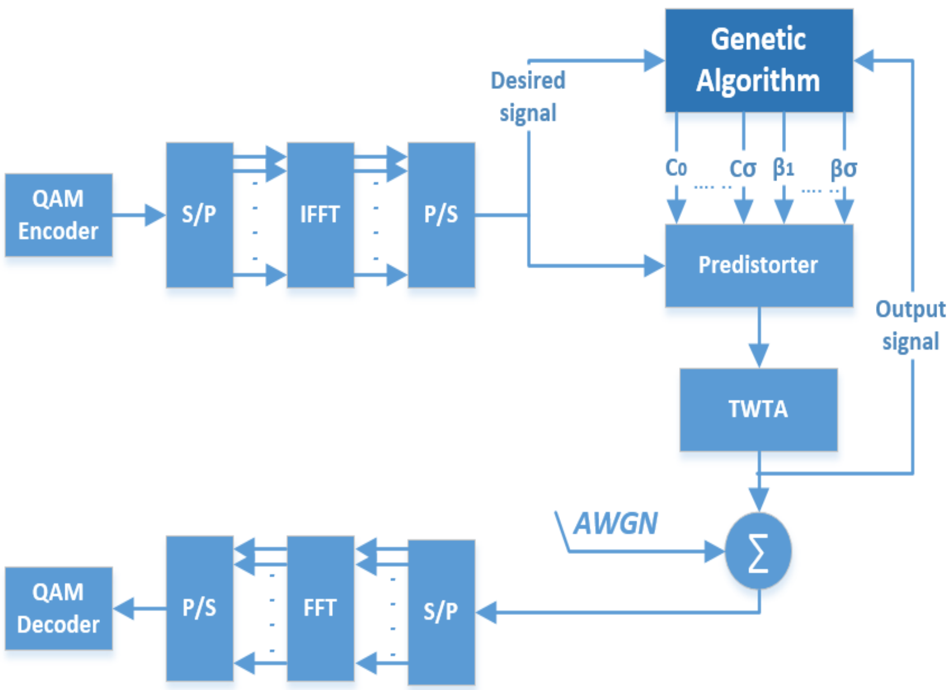

Figure 3. Block diagram of experiment setup for the execution evaluation of the predistorter.

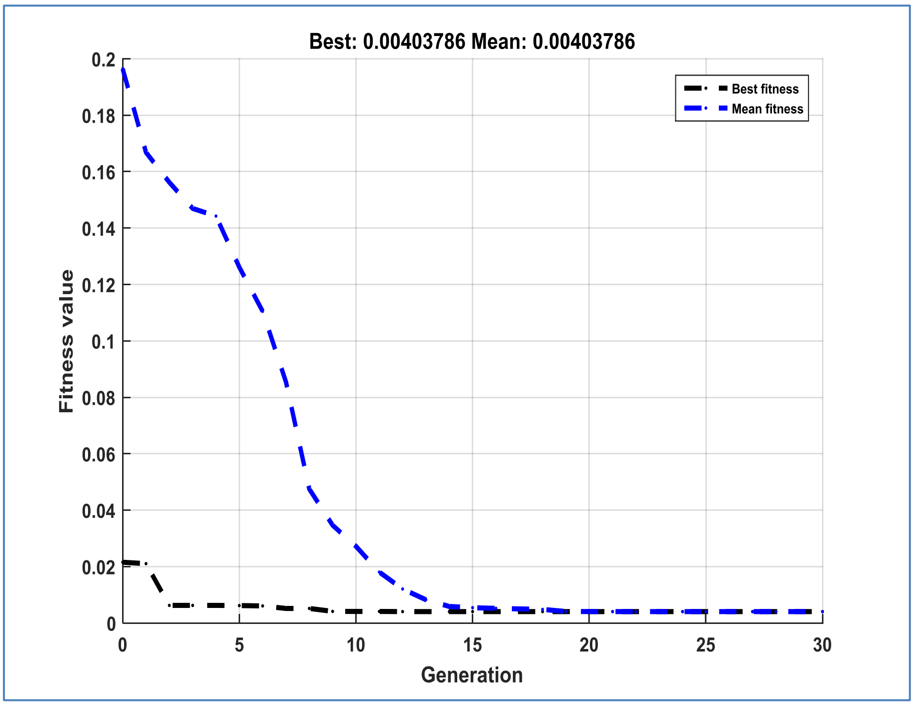

Figure 4. Fitness function behavior.

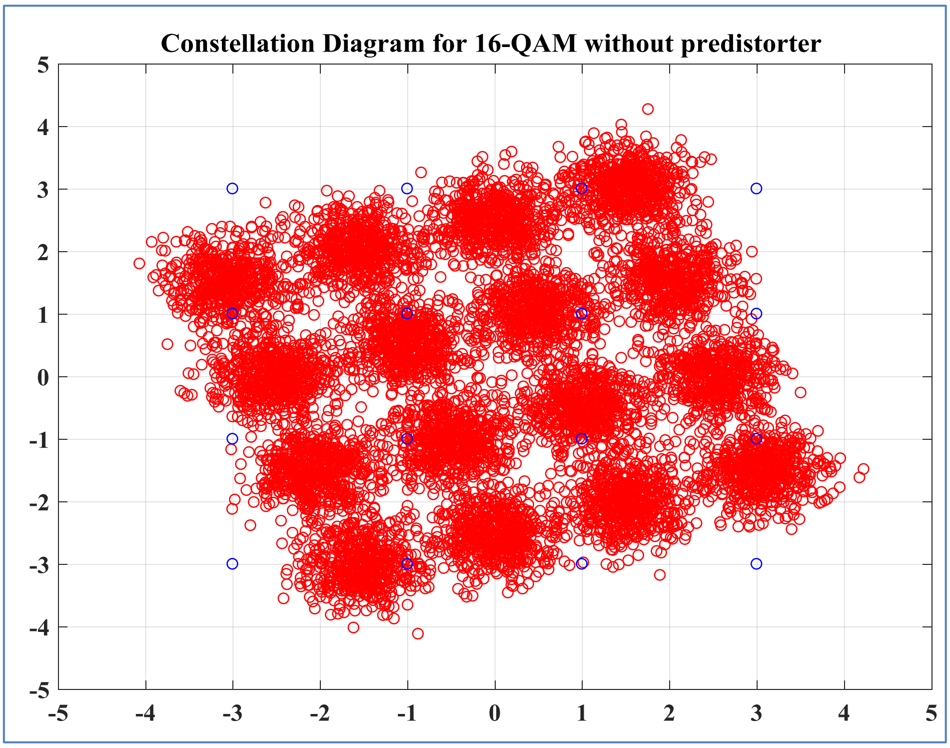

Figure 5. Constellation diagram of the 16-QAM Modulation scheme without a Predistorter at SNR=20dB.

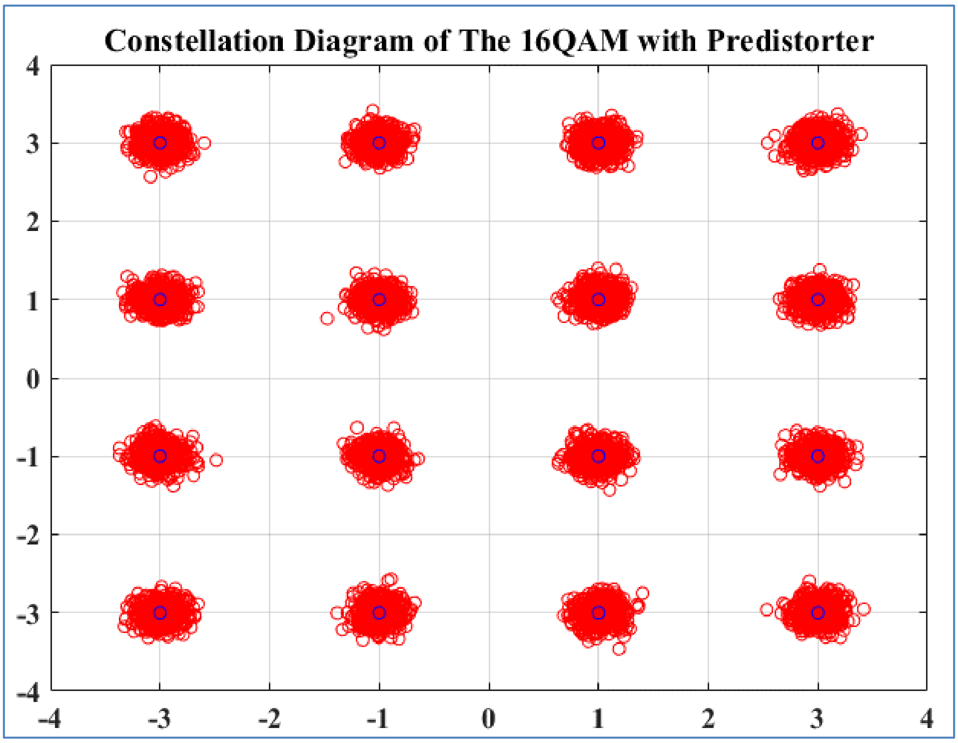

Figure 6. Constellation diagram of the 16-QAM Modulation scheme with a Predistorter at SNR=20 dB.

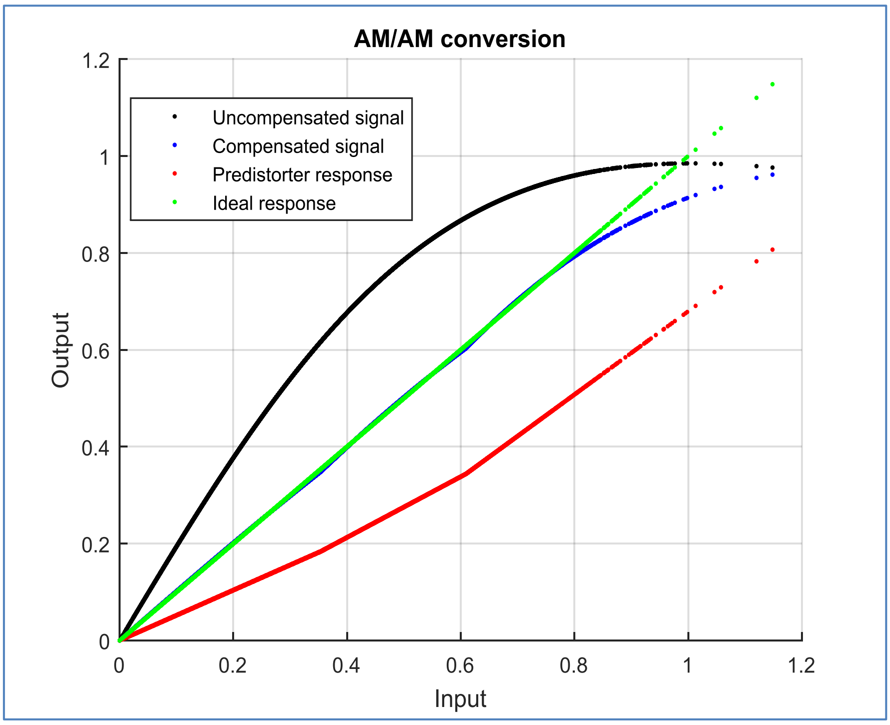

Figure 7. AM\AM Converter.

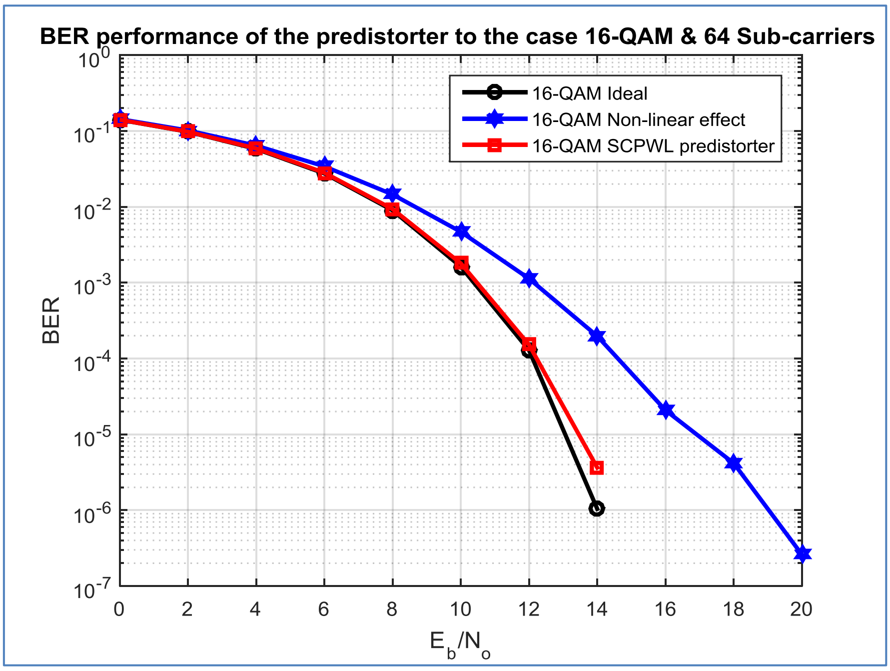

Figure 8. The performance of 16-QAM.

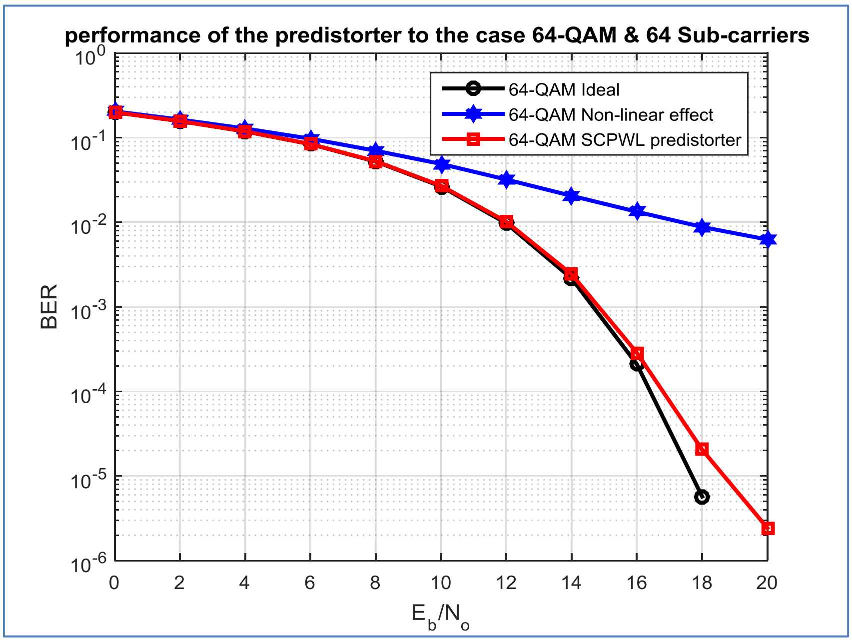

Figure 9. The performance of 64-QAM.

Appendix for the fitness function

```
function [y]=fan(c)
load s        %load for the OFDM signal
en=1.16 ;     % β_σ
cc=c(1:end/2);%Optimum coefficients of the SCPWL Model[c1 c2 c3]
```

```
Bi=c(end/2+1:end);% Optimum predefined partition point[β1 β2 β3]
co=0;
beta=0.99;      %βa
alpha=1.96;     %αa
bet=2.82;       %βө
alph=2.53;      %αө

for u=1:length(s)
   if s(u)<=en
   yt(:,u)=0.5*(s(u)-Bi+abs(s(u)-Bi));
   v(u)=co+ cc*yt(:,u);
   elseif s(u)>0.99*en
   yt(:,u)=0.5*(0.99*en-Bi+abs(en-Bi));
   v(u)= co+ cc*yt(:,u);
   end
end
A=(alpha*v)./(1+beta*v.^2);
y=mean(abs(s-A));  % Fitness function
```