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Artificial Bee Colony for Pre-Distortion of Nonlinear Power Amplifiers

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Abstract **– Power amplifiers are indispensable components in a communication system and are inherently nonlinear. A high power amplifier might exhibit limiting and saturation, when the amplitude or power is very large. Nonlinearities in communication systems may be either baseband or band pass. To improve the power amplifier efficiency without compromising its linearity, power amplifier linearization is essential. The inflexibility in defining the system for analysis or processing is the major drawback associated with these approaches and most of the works use analytical functions to be minimized; however, there is a lack of procedures or steps for effectively minimizing the function with various constraints. In this paper, Artificial Bee Colony (ABC) algorithm to overcome the lagging performance of the linearity problem in mapping that exists. Therefore ABC algorithm is proposed to rectify and find a better solution for the minimization functions. Many computational complexities which affect the performance of the pre-distortion will be avoided. The new technique will be enhanced with a criterion that reduce the computational complexities and overcomes the overall prevailing problems.**

Keywords **– Artificial Bee Colony, Linearity, Nonlinear, Optimization, Power Amplifiers, Pre-Distortion.**

I. Introduction

Power amplifiers (PA) generally exist in the transmitters, and are developed to increase the power level of the signal prior to sending it to the antenna. PA also shows memory effects [1]. PAs are essentially nonlinear and are essential elements in a communication system. Amplifiers that are highly linear, at the same time highly efficient does not exist. Time variant characteristics are exhibited by PAs because of temperature changes and aging . Wireless base stations have applications for PAs. Though linear operation can be achieved by linearization i.e., by biasing a power device for conduction in its linear region over the entire swing of the input signal waveform, it has low efficiency. An amplifier can be an effective solution if power consumption, size, weight and thermal factors can be tolerated [2]. Pre-distortion method is the cheap solution for reasonable performance improvement among the diverse methods available for linearising nonlinear RF amplifiers. Compared to feed forward, it has the extra benefits of reduced power consumption and uncomplicated circuit configuration.

In such an environment, pre-distortion technique can hopefully compensate for PA nonlinearities. Since PA linearization methods have the potential to solve this problem they are very attractive. Changeable signal envelopes in spectrum efficient modulation varieties used in new generation Communication systems is the reason behind the high importance of PA linearity. PA starts to manifest memory effects as the signal bandwidth becomes broader. Linearization techniques maintain the linearity of PAs to improve the efficiency. Functioning of the amplifier at low output level is necessary for the amplifier to have sufficient linearity. Generation of unwanted signal energy at frequencies not contained in the original signal is called distortion. Loss of linearity causes distortion. The degree of resemblance of the input-output transfer response of an amplifier to a straight-line is termed as amplitude linearity [1]. The Pre-distorter compensates for the nonlinear distortion introduced by the PA by accordingly distorting the input signal.

The pre-distortion concept is to employ an extra device called pre-distorter with inverse characteristics of those amplifiers and distort the HPA input signal. A pre-distorting amplifier is connected in front of the main amplifier by the pre-distortion technique. This extra amplifier has an inverse output distortion characteristics to that of the compressive main amplifier i.e., it has compressive instead expansive nonlinearity. The main RF amplifier produces linear and distortion-free output as these two nonlinear distortions cancel each other when added. Initial LUTs are produced at diverse short-term average power levels by determining the power ranges of LUTs. All LUTs are initialized to maintain input signal when the pre-distorter starts training mode [3]. The original input is amplified by a constant gain as the cascade of the pre-distorter and the PA becomes linear. The efficiency of the PA is considerably improved by the pre-distorter as the PA can be utilized up to its saturation point at the same time preserving a good linearity [5]. The design of an economical and high-performance adaptive digital baseband pre-distorter enables minimizing costly factory calibration necessities. These features make this work highly attractive for satisfying the stringent linearity requirements of the contemporary third and fourth generation (3G/4G) wireless systems, which realize superior spectral efficiency by utilizing complex amplitude and phase domain modulations [4]. Today, digital envelope domain employs Pre-distorters. The original in-phase/quadrature (I/Q) baseband signals are pre-processed in these systems e.g., the pre-distorted signals generated by adjusting the inverse characteristics of PA [10].

A. ABC Algorithm

Artificial Bee Colony (ABC) is a novel optimization algorithm inspired of the natural behavior of honey bees in their search process for the best food sources. In the ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts [7] [8]. At the initialization step, a set of food source positions are randomly produced and also the values of control parameters of the algorithm are assigned. The nectar amount retrievable from food source corresponds to the quality of the solution represented by that food source. So the nectar amounts of the food sources existing at the initial positions are determined. A bee waiting on the dance area to obtain the information about food sources is called an onlooker, a bee going to the food source is named as an employed bee, and a bee carrying out random search is called a scout.

The rest of the paper is organized as follows: Section 2 describes the proposed technique. Section 3 gives results and discussions.

II. Proposed Methodology

The input to baseband nonlinearity is a real valued signal $x(t)$ and its output is also a real-valued signal, $y(t)$. The nonlinearity is modeled as $y(t) = f(x(t))$. The most commonly used models of baseband nonlinearities are the power series model and the limiter model. The power series model is defined by

$$y(t) = \sum_{k=0}^{N} b_k x^k(t) \tag{1}$$

And the general limiter model has the form:

$$y(t) = \frac{M\,\mathrm{sgn}(x(t))}{[1+(\frac{m}{|x(t)|})^s]^{1/s}} \tag{2}$$

M is the input limiting value and s is the shape parameter. The normalized input-output relationship for a limiter is given for different values of S, Note that $s = \infty$ corresponds to a soft limiter and $m = 0$ corresponds to a hard limiter. Also note that with $m = 0$, the value of s has no effect on the characteristics of the nonlinearity. Therefore in our proposed work we are going to optimize the vector of shape factors using ABC algorithm. The following steps show how it optimizes using artificial bee colony algorithm.

A. Proposed Artificial Bee Colony for Optimization of shape factor:

The main steps of the ABC algorithm are given below:

- Initialize.
- REPEAT.
- Place the employed bees on the food sources in the memory;
- Place the onlooker bees on the food sources in the memory;
- Send the scouts to the search area for discovering new food sources.
- UNTIL (*requirements are met)*

Employee Bee Phase

The colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts [9]. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by itself previously is named an employed bee. A bee carrying out random search is called a scout. First half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive.

The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout. In each cycle, the search consists of four steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods; determining the scout bees and then sending them onto possible food sources. Here, the position of a food source represents a possible solution of the optimization problem and the nectar amount of a food source corresponds to the fitness of the associated solution. The number of the employed bees or the onlooker bees is equal to the number of solutions in the population. In employee bee phase, neighbor solution is generated based on ABC algorithm.

At the initialization stage, a set of food source positions are randomly selected by the employed bees and their nectar amounts are determined. Then, these bees come into the hive and share the nectar information of the sources with the onlooker bees waiting on the dance area within the hive. Initially, ABC generates a randomly distributed initial population represented by pop_{ini} having N_p solutions where each solution is the food source position and N_p is the population size. Each solution is represented by g_j, where $1 \le j \le N_p$ is a M-dimensional vector, where M is the number of optimization parameters taken into consideration. After initialization, the population of the positions is subjected to repeated cycles of the search processes of the employed bees, the onlooker bees, and scout bees.

Onlooker Bee Phase

In this phase, selection of the food sources by the onlookers after receiving the information of employed bees and generation of new solution is carried out. The onlooker bee prefers a food source area depending on the nectar information distributed by the employed bees on the dance area. As the nectar amount of a food source increases, the probability with which that food source is chosen by an onlooker increases, too. Hence, the dance of employed bees carrying higher nectar recruits the onlookers for the food source areas with higher nectar amount.

An onlooker bee chooses a food source depending on the probability value associated with that food source (P_j) given by the expression:

$$P_j = \frac{F_j}{\sum_{k=1}^{N_P} F_k} \tag{3}$$

Where,

F_j is the fitness value of the solution j Evaluated by its employed bee, which is proportional to the nectar amount of the food source in the position j

N_p is the number of food sources which is equal to the number of employed bees.

After arriving at the selected area, onlooker chooses a new food source in the neighborhood of the one in the memory depending on visual information. Visual information is based on the comparison of food source positions. When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one. An artificial onlooker bee probabilistically produces a modification on the position (solution) in her memory for finding a new food source and tests the nectar amount (fitness value) of the new source (new solution).

In case of real bees, the production of new food sources is based on a comparison process of food sources in a region depending on the information gathered, visually, by the bee. In our case, the production of a new food source position is also based on a comparison process of food source positions. However, in the model, the artificial bees do not use any information in comparison. They randomly select a food source position and produce a modification on the one existing in their memory. Provided that the nectar amount of the new source is higher than that of the previous one the bee memorizes the new position and forgets the old one. Otherwise she keeps the position of the previous one. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount and then, she produces a modification on the position (solution) in her memory and checks the nectar amount of the candidate source (solution). Providing that its nectar is higher than that of the previous one, the bee memorizes the new position and forgets the old one. In other words, a greedy selection mechanism is employed as the selection operation between the old and the current food sources.

Let the old position be represented by $z_{j,k}$ and the new position is represented by $y_{j,k}$, which is defined by the equation:

$$z_{j,k} = y_{j,k} + \varphi_{j,k}(y_{j,k} - y_{i,k}),\ i \neq j \qquad (4)$$

Where,

$$i = \{1,2,\ldots,N_p\}$$
$$k = \{1,2,\ldots,M\}$$

$\varphi_{j,k}$ is a random number in the range [−1, 1].

Which controls the production of a neighbor food source position around $y_{j,k}$ and the modification represents the comparison of the neighbor food positions visually by the bee.

The position update equation shows that as the difference between the parameters of the $y_{j,k}$ and $y_{i,k}$ decreases, the perturbation on the position $y_{j,k}$ also decreases, too. Thus, as the search approaches to the optimum solution in the search space, the step length is adaptively reduced.

Rearranging the position updating step, we have:

$$z_{j,k} - y_{j,k} = \varphi_{j,k}(y_{j,k} - y_{i,k}) \qquad (5)$$

As $z_{j,k}$ is the position update from $y_{j,k}$ in the previous step, representing in the time domain, we can write $y_{j,k}$ as z_t when $z_{j,k}$ is taken as z_{t+1}. Hence we have:

$$z_{t+1} - z_t = \varphi_{j,k}(y_{j,k} - y_{i,k}) \qquad (6)$$

The left side $z_{t+1} - z_t$ is the discrete version of the derivative of order $\alpha = 1$. Hence we have:

$$D^{\alpha}[z_{t+1}] = \varphi_{j,k}(y_{j,k} - y_{i,k}) \qquad (7)$$

Scout Bee phase:

The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout and it carries out random search. The food source whose nectar is abandoned by the bees is replaced with a new food source by the scouts [6]. This is simulated by randomly producing a position and replacing it with the abandoned one. Here, if a position cannot be improved further through a predetermined number of cycles called limit then that food source is assumed to be abandoned. In the classic ABC algorithm a scout searches the vicinity of the hive in a random way. This exploration feature of scout can be beneficial in the initial iterations; however performing a completely random movement in the final iterations may not be effective. Therefore in this approach, a scout explores the search space globally in the initial iterations and locally in the final iterations. Since in the last iterations improvement of the best food source may not happen, therefore it may be selected as a scout and removed from the population.

In order to avoid this problem, if the best food source is chosen as a scout, a greedy selection as in the case of employed bees and onlookers is performed. The control parameters used in the algorithm consists of the number of the food sources which is equal to the number of employed or onlooker bees, the value of limit, and the maximum cycle number. Here, the onlookers and employed bees carry out the exploitation process in the search space; the scouts control the exploration process and better the solution.

III. Experimental Results and Discussions

The results obtained for the proposed ABC algorithm is discussed in this section. The proposed technique is implemented using MATLAB on a system having the configuration of 6 GB RAM and 2.8 GHz Intel i-7 processor.

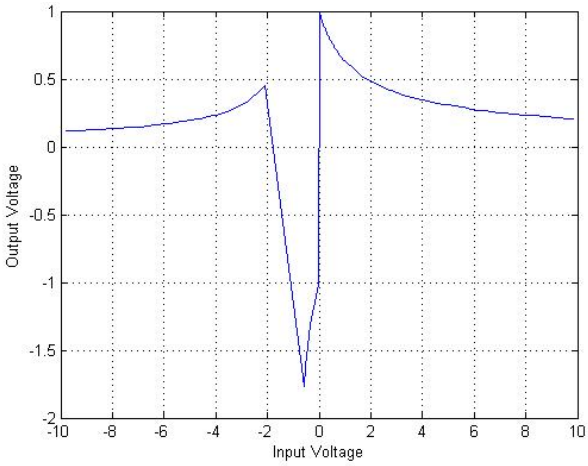

Fig.1. Limiter characteristics for 1st best solution

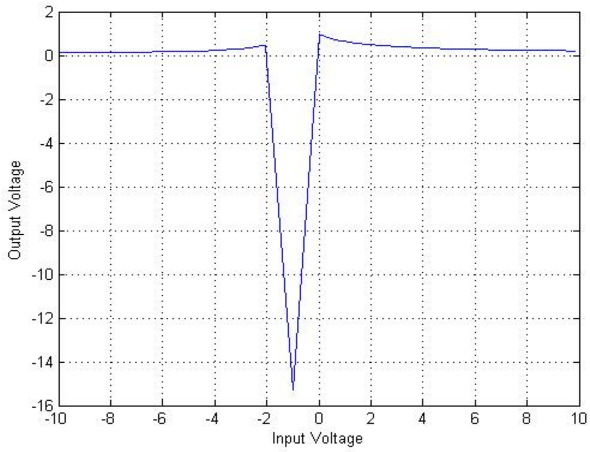

Figure 2: Limiter characteristics for 2nd best solution

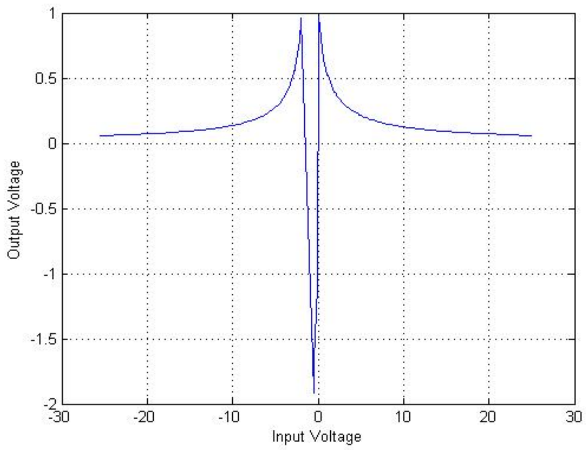

Fig.3. Limiter characteristics for 3rd best solution

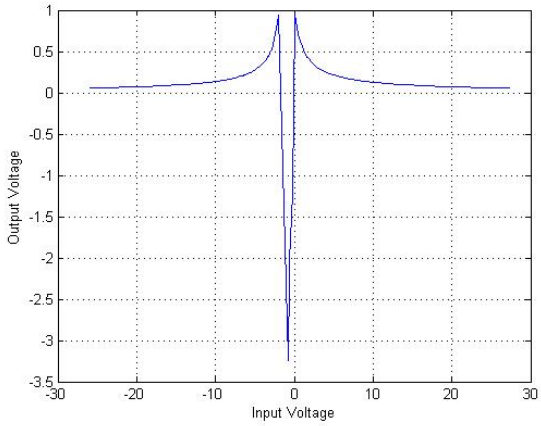

Fig.4. Limiter characteristics for 4th best solution

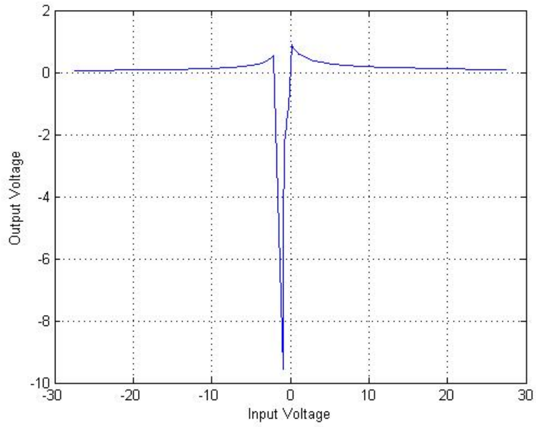

Fig.5. Limiter characteristics for 5th best solution

Table 1: Best fitness Solution for different shape vectors

S_1	S_2	S_3	Best Solution
0.5	1	10	1.16316
0.1	1	10	1.258729
0.4	1	10	4.794534
1	1.2	9	2.704745
0.11	1.3	9.2	8.634614

The fitness obtained with respect to the iteration count is taken for five test functions. Our aim is to find a better solution for the minimization functions and the computational complexities which affect the performance of the pre-distortion. Figure 1 to 5 gives the limiter characteristics for the best fitness solutions. Figure 1 to 5 is plotted for input voltage and output voltage. Table 1 shows the best fitness Solution for different shape vectors

We can see from all graphs, that our proposed technqiue have achieved better minimization functions. Result shows better performance for our proposed optimization technique. The technqiue performed well for all the input functions and proved its effectiveness and robustness of the porposed technique.

IV. Conclusion

In this paper, an optimization algorithm is proposed using Artificial Bee Colony for optimization to solve the existing problems. The proposed algorithm has three phases such as, employee bee, onlooker bee, and scout bee. The proposed algorithm is implemented in MATLAB. The proposed work presents the linearization techniques for power amplifiers. Thus ABC algorithm is proposed to find a better solution for the minimization functions and the computational complexities which affect the performance of the pre-distortion will be avoided. For experimentation, best fitness solution is found out for different shape vectors. From the results, we can see that the proposed technique has obtained better results by acquiring better solution.

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