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Linearization of High Power Amplifier Using Modified Artificial Bee Colony and Particle Swarm Optimization Algorithm

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Abstract

A linearization method for power amplifiers is proposed to cancel out distortion induced during amplification. Wiener model is chosen for power amplifier modelling. The linearization is achieved by the Modified Artificial Bee Colony (ABC) and Particle Swarm Optimization (PSO) algorithm. The Modified ABC and PSO algorithm reduces the complexity in linearization. Experimental results obtained for the proposed method shows that a better linearization of the amplifier characteristics can be obtained using the proposed method.

Keywords: Optimization, Artificial Bee Colony algorithm, Particle Swarm Optimization, Wiener model

1. Introduction

Power amplifiers are unavoidable components in every transmission systems and are nonlinear in nature. The nonlinearity leads to widening of signal bandwidth above the allotted limits, which leads the transmission to interfere with nearby channels. It also causes distortions within the signal bandwidth, which reduces the bit error rate at the receiver. Newer modulation formats, such as WCDMA or OFDM, are especially vulnerable to the nonlinear distortions due to their high peak-to-average power ratios (PAPRs). We can simply back-off the input signal to achieve the linearity required for the power amplifier, but this result in low power amplifier efficiency. Alternatively we can linearize a nonlinear power amplifier so that overall we have a linear and reasonably efficient...
transmission system. Digital pre-distortion (DPD) is one of the most cost effective ways [1] among all linearization techniques. However, most of the existing designs treat the power amplifier as a memoryless device. For wideband or high power applications, the power amplifier exhibits memory effects, for which memoryless pre-distorters can achieve only limited linearization performance.

The DPD scheme adds a digital pre-distorter in the baseband to create an expanding nonlinearity that is complementary to the compressing characteristic of the power amplifier. The combination of the pre-distorter and the power amplifier becomes linear and the original input is amplified by a constant gain [2]. With the pre-distorter, the power amplifier can be utilized up to its saturation point while still maintaining a good linearity, thereby significantly increasing its efficiency. In reality, the power amplifier characteristics may change over time because of temperature drift, component aging, etc. Therefore, the pre-distorter should also have the ability to adapt to these changes.

Digital pre-distortion implementations mostly focus on the power amplifier that has a memoryless nonlinearity; i.e., the current output depends only on the current input through a nonlinear mechanism. This instantaneous nonlinearity is usually characterized by the AM/AM and AM/PM responses of the power amplifier, where the output signal amplitude and phase deviation of the power amplifier output are given as functions of the amplitude of its current input. As the signal bandwidth gets wider, such as in WCDMA, power amplifiers begin to exhibit memory effects. This is especially true for those high power amplifiers used in wireless base stations. The causes of the memory effects can be attributed to thermal constants of the active devices or components in the biasing network that have frequency dependent behaviors. As a result, the current output of the power amplifier depends not only on the current input, but also on past input values. In other words, the power amplifier becomes a nonlinear system with memory. For such a power amplifier, memoryless pre-distortion can achieve only very limited linearization performance. Therefore, digital pre-distorters also need to have memory structures.

2. Literature survey

Sheng Chen [1] has suggested that digital pre-distorter remedy is alluring on account of its minimal on-line computational complexity, insignificant memory-units needed and the easy VLSI hardware configuration execution. In addition, the devised pre-distorter is competent to efficiently recompense the grave nonlinear distortions and memory impacts triggered by the memory HPA functioning in the output saturation horizon. The replication outcomes achieved are listed out to authenticate the efficacy of the innovative pre-distorter design.

Biyi Lin, Yide Wang, Bruno Feuvrie and Qingyun Dai et al [2]. Power amplifier linearization techniques are very important to reduce the distortion of the transmitted signal and the adjacent band interference of users. As its facility of implementation, adaptive ability and high efficiency, the pre-distortion technology becomes the first choice to minimize the nonlinear distortions. A new technique, based on the pre-distortion principle for linearizing a power amplifier, which is modeled by a Wiener model, is proposed. The Wiener model is used to take into account the nonlinearities and the memory effects of the power amplifier. Also propose an efficient and original method for extracting the parameters of the power amplifier's Wiener Model. Simulation results have been provided for showing the performances of this technique.

Bipin P.R and P.V Rao [3] has compared the use of ABC and PSO algorithms for the purpose of linearization of power amplifiers. From the experimental results they have found that the PSO algorithm provides good results compared to ABC algorithm.

Landin et al. [4] proficiently launched a direct model structure for defining the class-D out phasing power amplifiers (PAs) and a novel method for digitally pre-deforming these amplifiers. The direct model configuration was dependent on the modeling divergences in gain and delay, nonlinear interfaces between the two paths and divergences in the amplifier attitude. The digital pre-deformation technique was devoted to function only on the phases of input signal, duly rectified for both amplitude and phase mismatches. This eventually dispensed with the requirement for the supplementary voltage supplies to recompense for the gain mismatch. The Model and pre-deformation functioning were effectively evaluated on a 32 dBm peak output power, class-D out phasing PA in CMOS with on-chip transformers.
3. Artificial Bee Colony Algorithm

The ABC algorithm is a swarm based, algorithm based on the foraging behavior of honey bee colonies. The ABC consists of three groups [3,5] of artificial bees: employed foragers, onlookers and scouts. The employed bees comprise the first half of the colony whereas the second half consists of the onlookers. The employed bees are linked to particular food sources. In other words, the number of employed bees is equal to the number of food sources for the hive. The onlookers observe the dance of the employed bees within the hive, to select a food source, whereas scouts search randomly for new food sources. Analogously in the optimization context, the number of food sources (that is the employed or onlooker bees) in ABC algorithm, is equivalent to the number of solutions in the population. Furthermore, the position of a food source signifies the position of a promising solution to the optimization problem, whereas the quality of nectar of a food source represents the fitness cost (quality) of the associated solution.

The search cycle of ABC consists of three rules:

(i) Sending the employed bees to a food source and evaluating the nectar quality;
(ii) Onlookers choosing the food sources after obtaining information from employed bees and calculating the nectar quality
(iii) Determining the scout bees and sending them onto possible food sources.

The positions of the food sources are randomly selected by the bees at the initialization stage and their nectar qualities are measured. The employed bees then share the nectar information of the sources with the bees waiting at the dance area within the hive. After sharing this information, every employed bee returns to the food source visited during the previous cycle, since the position of the food source had been memorized and then selects another food source using its visual information in the neighborhood of the present one. At the last stage, an onlooker uses the information obtained from the employed bees at the dance area to select a food source. The probability for the food sources to be selected increases with increase in its nectar quality. Therefore, the employed bee with information of a food source with the highest nectar quality recruits the onlookers to that source. It subsequently chooses another food source in the neighborhood of the one currently in her memory based on visual information (i.e. comparison of food source positions). A new food source is randomly generated by a scout bee to replace the one abandoned by the onlooker bees.

4. Particle swarm optimization (PSO) Algorithm

Particle swarm optimization (PSO) is a population based stochastic optimization technique [5-9] developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called lbest. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest.

Basic Particle Swarm Optimization Algorithm In the basic particle swarm optimization algorithm, particle swarm consists of “n” particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition according to the following three principles: (1) to keep its inertia (2) to change the condition according to its most optimist position (3) to change the condition according to the swarm’s most optimist position. The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (near experience).

When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO. If the narrow surrounding is used in the algorithm, this algorithm is called the partial PSO.
5. Wiener Model

Wiener model consists of a LTI filter followed by a memory-less nonlinearity as shown in Fig.1. The LTI filter indicates the memory effect of the power amplifier and provides the required power amplification. The memory-less nonlinearity (NL) indicates the nonlinearity offered by the power amplifier.

Let \( x(n) \) be the input to the LTI filter, the output of the LTI filter is denoted by \( u(n) \). The output of LTI system is given as

\[
    y(n) = \sum_{k=0}^{K} h_k \cdot x(n-k) \tag{1}
\]

Where \( k \) indicates the number of samples taken, \( h_k \) denotes filter coefficients and \( x(n) \) denotes the input. The signal \( u(n) \) acts as input to the non-linear model without memory. The output of non-linear system can be written as

\[
    y(n) = \sum_{k=0}^{K} b_{2p-1} \cdot u(n) |u(n)|^{2(p+1)} \tag{2}
\]

Where \( b_{2p} \) indicates nonlinearity constants. After substituting \( u(n) \) in \( y(n) \) we can get

\[
    y(n) = \sum_{q=0}^{Q} h_q \cdot \sum_{p=0}^{P} b_{2p-1} \cdot |x(n-q)|^{2p+1} \cdot x(n-q) \tag{3}
\]

By selecting proper values for filter coefficients and nonlinearity constants a power amplifier can be modeled and can be used wherever a power amplifier is required to be considered.

6. Proposed Method

For enhancing the performance of power amplifier the Modified ABC-PSO algorithm and an adaptive technique has been used in pre-distortion technique. In the Modified ABC-PSO algorithm simultaneously both Modified ABC and Modified PSO algorithms are used together as shown in Fig.2. In Modified PSO best position of the samples are obtained as per the probability. After finding the best position, with normal PSO technique samples were replaced with best values. In modified ABC fitness of the samples of the signal are obtained. After finding the best fitness, with normal ABC technique samples were replaced with best values. Finally as per the power of the signals at the output of both algorithms, the signal that has best power value was taken as the output. This signal is the new reference signal and it is given to the adaptive filter as the reference signal input.

In Fig.3 the block diagram of proposed algorithm is shown. For measuring the performance of the proposed technique in wireless application, real-time sine signal has been generated.
Then the power of the generated signal has been calculated in dB and to improve the signal strength power has amplified using power amplifier. After power amplification nonlinearities are identified. For removing the nonlinearities in reference signal Modified ABC-PSO algorithm has been used.

Adaptive pre-distortion technique has taken the amplifier output as an input signal and Modified ABC-PSO output as a reference signal and it has replaced the linearity by subtraction. The output of the adaptive filter will be a linearized signal.

7. Results & Discussion

For checking the performance of proposed algorithm different frequencies signals has been provided from 1 Hz to 1GHz. Maximum gain offered by different algorithms are shown in Table.1. From the Table it has been observed that the modified PSO and ABC algorithm is giving positive gain in 100 Hz to 100MHz frequency range. The gain remains almost constant within this range also. All the wireless applications require a constant gain throughout its operating range. Therefore proposed algorithm is suitable for 100 Hz to 100 MHz spectrum and suitable for wireless application operating in this range.
Table 1. Power amplifier bandwidth calculation using different frequencies

| Frequency (Hz) | Input Power (db) | Amplified Power (db) | Modified PSO Power (db) | Modified ABC Power (db) | Modified PSO and ABC Power (db) | Output value |
|---------------|------------------|----------------------|------------------------|------------------------|--------------------------------|--------------|
| 1             | -30.06           | -161.1470            | -20.52                 | -29.13                 | -30.06                         | 0.09422      |
| 10            | -10.34           | -43.4092             | -0.8013                | -12.76                 | -0.8013                         | 3.522        |
| 100           | -6.021           | -2.7910              | 3.522                  | -6.021                 | 3.522                           | 3.522        |
| 1K            | -6.021           | -2.7910              | 3.522                  | -6.017                 | 3.522                           | 3.522        |
| 10K           | -6.021           | -2.7910              | 3.522                  | -6.022                 | 3.522                           | 3.522        |
| 100K          | -6.021           | -2.7910              | 3.522                  | -6.022                 | 3.522                           | 3.522        |
| 1M            | -6.021           | -2.7910              | 3.518                  | -6.016                 | 3.518                           | 3.518        |
| 10M           | -6.021           | -2.9912              | 3.137                  | -6.021                 | 3.137                           | 3.137        |
| 100M          | -189.8           | -10947               | -23.55                 | -23.55                 | -180.2                          | -9.75e-10    |
| 1G            | -187.7           | -1008.3              | -23.52                 | -23.52                 | -179.9181                       | 9.75e-10     |

For evaluating the validity of the proposed system a signal of 1KHz has been generated and fed as input to the power amplifier model proposed. Power spectrum of the generated power signal and the corresponding output spectrum is shown in Fig.4 (a) and Fig.4 (b) respectively.

![Power Spectrum of Input Signal](image1)

![Power Spectrum of Power Amplifier Output](image2)

Fig. 4. (a) Power spectrum of input; (b) Spectrum of Power amplifier output

The output of the power amplifier using the Modified ABC-PSO algorithm is shown in Fig.5 and from this we can see that the required power has been filtered and small power variations are suppressed.
Fig. 5. Performance of Proposed algorithm

The relation between input and output power is illustrated in Fig. 6 and from this figure we can see that the characteristics of the proposed method is linear and the proposed method has provided good linearization.

Fig. 6. Relation between input and output power

8. Conclusion

Pre-distorters based on different identification methods are designed to compensate the distortions caused by power amplifier model with true output saturation characteristics. In identification work, Modified ABC and PSO algorithms are implemented to identify an accurate reference signal, based on which linearization can be directly obtained. The performance of the pre-distorters designed has been illustrated in the simulation results. In particular, it has been shown that the proposed linearization method is capable of successfully cancelling out serious nonlinear distortions caused by the power amplifier operating near the output saturation region.

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