Intelligent Optimization Methods for Analogue Electronic Circuits: GA and PSO Case Study

Ogri James Ushie, and Maysam Abbod

***Abstract*—**The paper presents a review of various swarm intelligence optimisation, the use of genetic algorithm (GA) and particle swarm optimisation (PSO) technique for optimisation of electronic circuit a case study; minimisation of a single stage common-emitter amplifier. The circuit was transform to small signal module while mesh analysis was applied to convert it to matrix form. Programs were coded in Matlab using GA and PSO technique to minimise the common-emitter circuit. Results, when compared to the original circuit show that both PSO and GA reduce power consumption. It further reviled that PSO was better than GA in terms of higher power reduction.

***Keywords*—**Common-emitter Amplifier, Genetic Algorithm, Particle Swarm Optimisation, Small Signal Module.

I. Introduction

MINIMIZATION of electronic circuits is required to reduce power consumption, reduce the value of component, and increase system reliability but that is not the case of amplifier. Amplifier is a device use to boast electrical signal. Most amplifier circuits consume high power; reduce system reliability and high component value.

Problems in society are being solved by studying the social behaviour of animals so their behavioural principles can be translated into algorithm. Individual within the group exchange information so that the problem is better solved than just one individual. In terms of definition, the group of animals is called a swarm while the individual animal is called a particle. Specifically, Swarm Intelligence (SI) ‘refers to the problem-solving behaviour that emerges from the interaction among the swarm’, [1] and Computational Swarm Intelligence (CSI) refers to the process of translating behaviour into algorithm for modelling.

Optimization is a branch of computational science which can be defined as the process of finding the best solution for a problem [1]. As long as society continue to exist and the quest to improve standard of living, problem can be found everywhere in life, including diverse field such as engineering, manufacturing, finance, medicine, computational art and music, physics and chemistry. The need to find the best solution is encountered in everyday life and cannot be overemphasized. There are different methods of optimization; namely: Bacterial Foraging (BFO), Ant Colony Algorithm (ACA), Artificial Bee Algorithm (ABC), Fire Fly Algorithm (FFA), Genetic Algorithm (GA) (Evolutionary Algorithm, Genetic Folding and Genetic Programming) and Particle Swarm Optimization (PSO).

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This paper outlines intelligent methods that are used to optimise electronics circuits, giving the advantages and disadvantages of each. A case study was conducted on GA and PSO for the optimisation of power consumption of a BJT amplifier circuit.

II. Intelligent Optimisation Techniques

A. Bacterial Foraging Optimization (BFO)

The survival of an organism in its search for food and it related mobility depends upon their fitness criteria. It is inspired by the chemotatic behaviours of bacterial that will sense chemical gradients in the environment and move away or toward specific signals. The organism eliminates or redesigns weaker organism with poor search ability. The genes of those species that are stronger are used for evolution chain they have promising better species in future generations. A clear understanding of foraging behaviour in evolutionary species is being translated into algorithms and then applied to non-linear optimization problem. Full detailed Bacterial Foraging Optimization Algorithm is presented in [2], [3]. Bacterial Foraging has been successfully applied to quite a number of non-linear optimization problems which include;

The use of bacterial foraging for distributed optimization and control is presented in [2]. The paper states how foraging should proceed, at the same time translated it into computer program that imitate the distributed optimization process and suggested it as new optimization method. The approach was applied in uninhabited autonomous vehicle (UAVs) that find application in military and commercial use. BFA was developed for the optimization of Yagi-Uda array design in [3], 6 and 15 elements Yagi-Uda array designs were used as a model and it achieved global optimum which overcomes the problem of pre-mature convergence to local optima by evolutionary algorithm. This was achieved as a result of the special feature of BFA in term of elimination and dispersal processes. Result presented shows that BFA converges faster than GA; however, it was claims to be more suitable for complex large number of parameters of optimized. BFA is used in distributed control application in sensor network [4]. It was claim that it addresses the area where classical control theory is not sufficient in modelling. The approach buffer the incoming data for certain period of time to enable most of data

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arrived. Further work will be on implementation, verification, and testing of the approach in distributed control systems.

Furthermore, bacterial foraging Algorithm has been successfully used in the field of communication among which are; an improved adaptive Bacterial foraging Algorithm (ABFA) using the principle of adaptive delta modulation is presented in [5]. The null steering in radiation pattern was achieved by controlling both the amplitude and phase weight. Result presented shows improvement with the method when compared to non-adaptive algorithm in terms of convergence and quality of result. Multi-colony bacterial foraging optimization (MC-BFO) for complex radio frequency identification (RFID) network planning problem is in [6]. BFA was extended to the iterating multi-colony model by translating/relating chemotatic behaviour of a single bacterial cell to the cell-to-cell communication of bacterial community. It has the ability for solving more complex problem. Result presented shows its superior solution in network planning than PSO and GA in terms of optimisation accuracy and computational robustness.

Moreover, in power system, the use of BFA to optimize coefficient of the plus integral (PI) controller was introduced [7]. Result presented shows that BFA-IP was satisfactory and converged global optimum solution faster than GA. In another paper, Bacterial foraging Algorithm was used to minimize the real power loss and also improve the VSL of the system [8]. This was achieved as a result of using BFA technique in allocating UPFC and transformer taps which give a better result compared to IPSLP technique. Also used BFA for optimum location and injection of voltage for the UPFC and the quality taps shows that BFA was better than IPSLP [9] . Power system stability (PSS) was made stable when BFA was use to solve the unstable cases in CPSS and GAPSS [10]. Also an enhance PSS stable by using BFA in [11]. BFA in power system stability is Presented [12], [13]. Bacterial Foraging Optimization was used to train NN by [14] as well as result presented shows that BFO-NN approach produces quality result than GA-NN in terms of convergence and accuracy in short term load forecasting. Genetic Algorithm Bacterial Foraging Algorithm for PID controller of AVR system is proposed [15], [16]. Result were compared to GA, PSO GA-PSO shows it potential for optimisation.

B. Ant Colony Optimization (AC)

The foraging characteristics of real ants inspired the ant-based algorithms (AA) development. The ability of the ant to locate its food source and their nest through the shortest path was study and series of algorithms were developed [1]. Ant colony search algorithm (ACSA) for scheduling in thermal power generation by applying ant co-operation while developing the algorithm is in [17]. Results presented were compared with conventional scheduling method which demonstrates the suitability of the approach. Also apply ACA in scheduling the resource-constrained project and aluminium casting centre respectively in [18], [19]. Ant colony search algorithm (ACSA) has been used by different researchers in many fields among: An improvement on the algorithm and applied it to electromagnetic devices designs [20]. The used ACA in power electronic circuit design [21] was extended. Result resented shows better fitness values and faster when compared with GA approach. The result further implies that it can be used to solving both continuous- and discrete-valued parameters problem. It also minimizes both component values and the number of components.

Furthermore, Solution to vehicle routing problems was found with time window using ant colony algorithm [22]. It was achieved with two colonies, in which each colony minimizes the travelled distances and number of vehicles. Result presented shows that MACS-VRPTW is a good approach and has better results. A cooperative learning approach (ACS) to solve travelling salesman problem is presented in [23]. Results show that ACS is better than evolutionary computation and simulated annealing. Application of ACA to routing in Packet-switched networks and travelling salesman is in [24] .

In area of communication, ACA for wavelength allocation and virtual-wavelength-path routing is in [25]. Also Gunes M at al [26] applied the algorithm in mobile ad-hoc network (MANET), in the same routing application ACO was used in wireless sensor networks by [27], [28].

In addition, Ant colony algorithm has been applied in the following areas: Dynamic optimization of chemical process is applied in [29]. Data mining application was done by [30]. Industrial application in the area of travelling salesman problem and job shop scheduling problems by [31] and process engineering problem application by [32]

C. Artificial Bee Colony (ABC) Algorithm

It is a population-based, stochastic technique that performs a kind of neighbourhood search. The foraging process include; the scout bee go in search of flower patches (the number of bee sent is proportional to the amount of patches) and random search from one patch to another. Special features of honey bee such as communication, allocation of task, decision making, nest site selection, mating, marriage, reproduction and foraging are being translated into algorithm called bee algorithm [33]. The use of ABC in the design of CMOS inverter was proposed in [34], the MATLAB was use to code the ABC algorithm and the accuracy of result was compared to SPICE simulation and the result shows the capability of ABC for electronic circuit design. Their future work will be to expand investigating of propagation delay times. Other use of ABC algorithm in electronic circuit design includes [35]-[37]. The ABC algorithm is shown in [38], [39] in which the algorithm was used to optimize Nano-CMOS analogue and solved travelling salesman problems (TSP) respectively. Also the use ABC algorithm for scheduling in [40]-[42] while [43] use ABC algorithm for electric load forecasting. ABC algorithm in [44] was used for Structural optimization. The modified form of a best-so-far for solution update in the ABC algorithm was introduced in [45] and the author claim that the improved algorithm perform better than ABC algorithm.

D. Firefly Algorithm (FFA)

The amazing characteristic of firefly is the flashing light. The flashing pattern determines the species which are about two thousand in number [46]. The function of flash is to attract the potential prey, attract mating partner (communication) and to serve as warning mechanism. The summary of these features are:

(1) Flies attract to one another irrespective of sex.
(2) Attractiveness is proportional to brightness.
(3) Brightness is proportional to fitness function.

The flashing characteristic inspired firefly algorithm used in optimization. The algorithm is shown in [46], [47], the first provide a detailed firefly algorithm while the second show improvement of the algorithm. Result presented shows how PSO outperform firefly algorithm. Furthermore, Firefly algorithm was proposed in [48] to construct codebook of vector quantization. Result presented shows that the reconstructed images get higher quality than those generated from the LBG, PSO and QPSO. A decentralized algorithm for synchronicity based on firefly features is presented [49]. This algorithm was applied to sensor network and result shows that the algorithms can synchronize sensor network.

E. Genetic Algorithm

Genetic Algorithm is a population–based stochastic global search method that applies the principle of survival of fittest to produce better and better solution [50] . At very iteration, individuals are selected according to their level of fitness in the problem domain. The process generates population of individuals that are better suited to their environment. The individual are then encoded as strings, chromosome, composes over some alpha(s), so that genotypes are uniquely mapped [50]. After decoding the chromosome into decision domain, then the fitness is evaluated which serve as criteria for selection of pairs of individuals for the next reproduction. The following are genetic algorithm operators; selection, crossover, and mutation.

GAs use potential solutions, called a population composing between 30 to 100 individuals, although micro GA uses small population (-10 individuals) [50]. Chromosomes commonly are represented in GA as single-level binary string, Gray coding, and real number representation detailed in [50].

GA algorithm has been used in many applications [50]-[53], GA is proposed as design tools for industrial engineers [51]. Electromagnetic genetic algorithm optimization (EGO) is proposed in [54] . EGO was used in field of wireless communication to design a dual-band antenna element. GA was used for optimal placement of capacitor in radial distributed system in [55, 56].

Genetic learning with a memory of past solution to problem which learns to improve quality of result for similar design problem is [57]. The algorithm was applied to parity checker and the result presented was improved. Also a GA application in digital circuit is in [58], [59].

In addition, Extension of algorithm of GA [60], from their previous work that allows parasitic effect in components to be included in analogue circuit designs. Filter circuit was used to demonstrate the approach which was successful. Other research in the use of GA to designing filter is in [61]-[65]. Also [64] apply the algorithm to design of amplifier but with the limitation and further as follow: inherent restriction on circuit topologies in the approach. The future work will be to design an amplifier that would require using a multi-objective fitness function that accounts for each specification as well would perform.

Other analogue circuit include. The proposed of GA for optimization used in antenna design by matching network parameters is in [66] , location of the load along the antenna and loading circuit parameter. The GA guides a population of randomly generated individual toward the optimal solution. It was used to design broad-band antenna and their corresponding matching network. The application of GA in power electronic circuit optimization is in [67, 68] while an automated algorithm for optimization of analogue circuit is presented in [69]. SPICE simulated result serve as the fitness value for the algorithm. The automated algorithm for CMOS amplifiers using GP and current-flow analysis is in [70] and automated design combinational circuit using GA is shown [71].

F. Particle Swarm Optimisation

PSO is a population-based stochastic technique developed Kennedy and Eberhart 1995 [72] inspired by social behaviour of flock of bird or school of fish. In PSO populations of potential solutions called particles are flown in search of the required solution, each particle is updated in the process. The collection of particles together is called swarm. Detailed PSO algorithm is shown in [73] while improved PSO algorithm with leadership and parameter selection guide in [74], [75]. The concept of mutation and time varying coefficients called MPSO-TVAC was introduced in [76] while Modified PSO-TVAC is shown in [77]. PSO has been used for combinational circuit optimization as in [5], [73, [78]-[81]. Also Hybrid PSO is used in evolving digital circuit in [82] and PSO application in digital filter design is in [83].

PSO have been used by many researchers in analogue circuit application; [84] apply PSO algorithm in analogue circuit to diagnose soft fault. The principle of nodal voltage equation was used constraint of the linear programming equation. Result was presented to show the potential of the method. PSO applied to cancel acoustic echo is illustrated in [85], also used for local positioning system [86] and target tracking as in [87].

PSO was presented as another method to genetic algorithm (GA) for manufacturing tolerance [88], as make up for aging, temperature distribution inside the chip, or additional factors of the external environment of field programmable analogue scalable device array (FPADA). PSO was used as a new application to design an operational amplifier. Result presented shows a better, faster and easier to implement solution than the GA. The use of PSO to design an inverter is in [89] while the application in microwave amplifier is described in [90], [91].

Particle swarm optimization (PSO) for design of analogue circuits is proposed in [92]. Analogue signal processing finds many applications and widely uses OPAMP based amplifiers, mixers, comparators and filters. The quality of result was compared to simulated program with integrated circuit emphasis (SPICE). PSO technique gives accurate result and promising method for device sizing in an analogue circuit.

PSO approach to power electronics circuits (PECS) design [93] is presented. The approach was divided into two; firstly, decouple technique in which PSO is employed to optimise the values of the circuit components in the power conversion stage (PCS) and secondly, the feedback network (FN). Also mutation was introduced to PSO in order to diversify the population. The approach was applied to optimize bulk regulator. Result presented gives better circuit component values than that of GA approach.

PSO technique for the optimal design of analogue circuits [94] is used. The emphasis was on how suitability of PSO to solve both mono-objective and multi-objective discrete optimization problem. Two application examples were presented; maximizing the voltage gain of a low noise amplifier for the Universal Mobile Telecommunication System (UMTS) standard and computing bi-objective problem, maximizing the high current cut off frequency and minimizing the parasitic input resistance of a second generation current conveyor and their future work focuses on integrating PSO approach in an automated design flow. Also a paper on how analogue circuit performance can be improved by PSO algorithm [95] is presented.

Furthermore, PSO algorithm has been proposed for class E amplifier [96]. In the paper standard commercial simulator was use to get the design parameter which was used as fitness function. Result presented confirmed with the simulated values while their further work will is to improve on the algorithm. The PSO algorithm was improved in their further research [97]. Result presented confirmed that PSO approach was better than the standard one. Still their future work is to further improve on the algorithm, provide other constraints to the objective function.

PSO algorithm for nonlinear Laterally Diffused MOSFET (LDMOS) transistor modelling optimization is in [98]. The algorithm was used to design power amplifier with both microstrip and BALUN matching network. Consequently the amplifier is unconditionally stable and linear over UHF frequency range of 100 MHz to 1 GHz. It was further stated that, an UHF amplifier was optimized with broadest linear respond and high efficient performance. The power gain of 12 dB, power added efficiency (PAE) of the power amplifier was 55% and 33 dBm output power

Minimization of electronic circuits is required to reduce power consumption, reduces the size of component, and increase system reliability but that is not the case of amplifier. Amplifier is a device use to boast electrical signal. Most amplifier circuits consume high power; reduce system reliability and higher component size. Although ref. [64] uses GA to optimize amplifier and ref. [98] uses PSO to evolve amplifier circuit. Despite this improvement, none of such technology had been carried out in area of amplifier power reduction.

III. Optimisation Of Common-Emitter Circuit Using GA And PSO

A single stage common-emitter amplifier is used as a case study. The circuit is shown in Figure 1. The transistor is transform to small signal module; while mesh analysis is apply to convert the circuit into matrix form. Programs were written in Matlab using GA and PSO technique to minimise the common-emitter circuit.

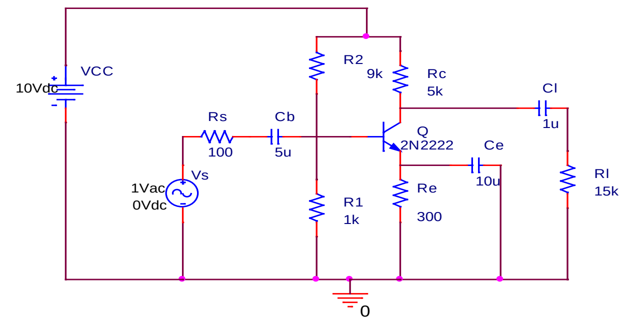

Fig. 1 Common-emitter amplifier.

III. Results and Discussion

The result obtained from the simulation is shown in Table I. The original circuit is simulated in PSICE to obtained frequency response, bandwidth and power. It has shown that PSO and GA is a minimisation tool for electronics components. Result when compared to the original circuit shows that both PSO and GA reduces power consumption. It further reviled that PSO was better than GA in terms of higher power reduction. Result presented for both PSO and GA, PSO power was less than that of GA. Parameter setting in GA were; population size = 20, crossover = 0.8, generation = 100 and mutation = 0.05. While PSO parameters were; acceleration constants (c1 & c2) =1.49618, initial weight (w) = 0.7298, number of iteration = 50, number of particles = 20.

TABLE I
SIMULATION RESULTS

Circuit element	Initial Circuit	GA Circuit	PSO Circuit
Rl (Ω)	15k	14.44k	13.82k
Re (Ω)	300	219	244
Rc (Ω)	5k	4.78k	4.98k
Rs (Ω)	100	100	102
R1 (Ω)	1k	851	690
R2 (Ω)	9k	8.22k	6.83k
Fl (Hz)	610.34	610.24	610.34
Fh (Hz)	1.3813M	1.4398M	1.4394M
Power (mW)	21.44	20.95	20.05

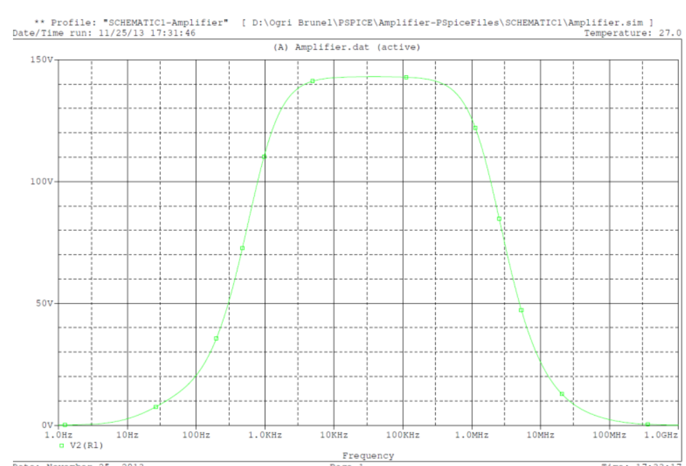

Fig. 2 Frequency response curve for initial circuit.

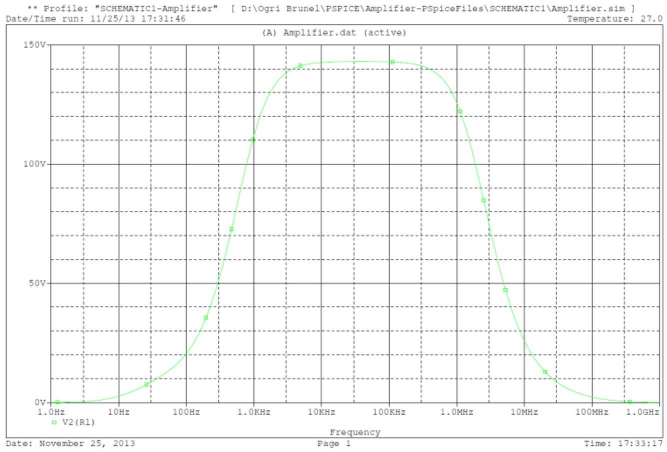

Fig. 3 Frequency response curve for GA circuit.

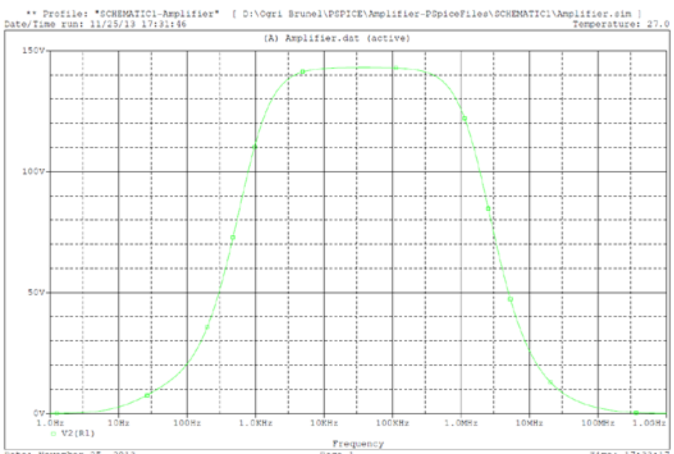

Fig. 4 Frequency response curve for PSO circuit.

Figures 2, 3 and 4 show frequency response curves for initial, GA and PSO optimised circuits respectively.

IV. Conclusion

The paper attempt to review of various swarm intelligence optimization with a case study of PSO and GA. Minimisation of a single stage common-emitter amplifier is use as example. Results were presented and compared to the original circuit which shows that both PSO and GA reduce power consumption. It further reviled that PSO is better than GA in terms of higher power reduction.

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