Optimization of Low Noise Amplifier Designs by Genetic Algorithms

Hao-Hui Chen, Ming-Huei Chen, Cheng-Yu Tsai

Abstract—The genetic algorithms (GAs) are employed as an optimization tool for low noise amplifier (LNA) designs. In the optimization, the input and output matching circuits for an LNA are encoded by a chromosome representation. A fitness function is then defined to quantitatively measure the circuit performances of the LNA. Following the evolving processes of the GAs, the matching circuits can be optimized to obtain a high-performance LNA. To demonstrate the optimization algorithms, 2.4 and 5.2 GHz LNAs are designed and implemented. For both the examples, the GAs take about 70 iterations to acquire the optimal results. In addition, the simulated and measured results show that the obtained LNA designs well satisfy the desired design targets, which validate the capability of GAs in the LNA designs.

I. INTRODUCTION

With the rapid growth of the applied electromagnetics, various optimization techniques such as the particle swarm optimization [1][2], space mapping technique [3][4], neural networks [5][6], and genetic algorithms (GAs) [7][8] have been developed to deal with complex electromagnetic problems. Among these electromagnetic-optimization studies, one important topic is using the GAs to optimize RF/microwave circuit designs. The GAs were introduced in 1975 and have been successfully applied in the designs of microwave filters, diplexers, and antennas. The majority of research, however, has focused on the treatment of passive circuit designs. Designing an active microwave circuit by the GAs is still relatively scarce. To apply the GAs to the LNA optimization designs, the input and output matching circuits need to be considered simultaneously in the LNA designs, fine tuning and optimization are usually required to acquire a high-performance LNA.

To apply the GAs to the LNA optimization designs, the input and output matching networks (IMN and OMN) for an LNA are first encoded using a chromosome representation. A fitness function is then defined to quantitatively measure the circuit performances, including the input/output matching, power gain, and noise figure, of the LNA. Following the evolving processes, that is, crossover, mutation, and selection operations, the optimized IMN and OMN designs can be obtained by the GAs to acquire a high-performance LNA. To demonstrate the optimization algorithms, two LNAs for 2.4 and 5.2 GHz WLAN systems are considered in this study. The performances of the designed LNAs are simulated by the Agilent ADS circuit simulator. Also, the LNAs are fabricated and measured to perform the experimental verification. It is found that the IMN and OMN designs can be simultaneously and efficiently optimized by the GAs. For both the tested examples, the GAs take about 70 iterations to acquire the optimal results. Also, the simulated and measured results show that the designed 2.4 and 5.2 GHz LNAs well satisfy the desired design targets from 2.2 to 2.5 and 5.1 to 5.4 GHz, respectively.

II. GA SCHEME FOR LNA OPTIMIZATION

Fig. 1(a) shows a simple topology of the LNA design considered in this work. In this compact two-port circuit, the characteristics (including the S-parameters and noise parameters) of the RF transistor are first obtained from the data sheet or the measurement. The input and output matching networks are then designed to acquire the required circuit performances. Fig. 1(c) presents the circuit elements, including inductors $L$, capacitors $C$, and transmission-line segments, for constructing the matching networks. The electrical parameters of each element are also listed in the figure. To optimized the matching circuits by the GAs, the circuit elements are first encoded and represented by genes. A data structure, that is, a chromosome formed by the genes, is then applied to describe the matching circuits. Fig. 1(b) illustrates the chromosome representation of the matching circuits for the LNA shown in Fig. 1(a). In the chromosome, the first and second rows are the genes for the IMN. They describe the circuit design, including the circuit topology type and the corresponding electrical parameters, of the IMN. Similarly, the third and forth rows denote the genes for the design of the OMN. To keep the whole circuit compact, only four genes, i.e., four circuit elements are used to design the matching circuits in this study (two for IMN and two for OMN). More elements, if necessary, can be further applied for other designs and applications.

Having the chromosome representation of the matching circuits, the IMN and OMN are then decoded from a chromosome and cascaded with the transistor to obtain the overall performances of the LNA, from which the fitness function defined as
can be applied to quantitatively measure the quality of the chromosome. In (1), $f_{i,\alpha}$ ($\alpha = S_11, S_22, S_21$, and $NF$) is the square of the difference between the calculated $\alpha$ parameter and the desired value at the $i$-th sampled frequency point. $w_{i,\alpha}$ denotes the weighting for the $\alpha$ parameter at the $i$-th sampling point. $N$ is the number of the sampling points. It is worth noting that the first and second terms in the fitness function (\( w_{i,S_11}f_{i,S_11} \) and \( w_{i,S_22}f_{i,S_22} \)) describe the input and output matching conditions of the LNA. Meanwhile, the third and forth terms (\( w_{i,S_21}f_{i,S_21} \) and \( w_{i,NF}f_{i,NF} \)) are used to measure the performance of the gain and noise figure, respectively.

Next, an initial population (first generation) of chromosomes is randomly generated. By evaluating the fitness of every chromosome, evolution is performed through the selection, crossover, and mutation processes to create new chromosomes in the next generation. (The detailed treatments of the evolution procedures can be found in [9].) The evolution is repeated until the maximum generation or the target fitness value solution is reached. In this work, the ranking selection scheme is adopted for the selection operation. The real-parameter evolving algorithms are used in the crossover and mutation processes. Also, the probabilities for performing the crossover and mutation are set to be 0.7 and 0.1, respectively.

III. DESIGN EXAMPLES

Two LNAs for 2.4 and 5.2 GHz WLAN systems are designed and implemented in this section. The design targets for the considered LNAs are taken as:

- **2.4 GHz LNA**: Input and output return loss $<-10$ dB, power gain $>20$ dB, and noise figure $<3$ dB, within the frequency band 2.2 – 2.5 GHz.
- **5.2 GHz LNA**: Input and output return loss $<-10$ dB, power gain $>10$ dB, and noise figure $<3$ dB, within the frequency band 5.0 – 5.3 GHz.
The RF transistors START540 and BFU725F were employed in the 2.4 and 5.2 GHz LNA designs, respectively. The circuit simulation was performed by the Agilent ADS simulator. Meanwhile, a FR4 substrate with dielectric constant $\varepsilon_r = 4.2$ and thickness $h = 0.8$ mm was used for the circuit fabrication.

Fig. 2 shows the convergence of the GA optimization for the investigated LNA designs, where the minimum fitness values ($F_{\text{min}}$) of the population at each generation are plotted as functions of generations. It is seen that the GA fitness values for both designs converge to a good result in about 70 generations. The $F_{\text{min}}$ reaches a minimum less than 0.0015 and 0.0055 for the 2.4 and 5.2 GHz cases, respectively. In addition, it is worth mentioning that the algorithm is very efficient. The computing time of the generation evolution process is about 3 minutes for both the tested examples. The final design results obtained by the GA optimization are displayed in Fig. 3, where the design parameters as well as the corresponding circuit schemes for the 2.4 and 5.2 GHz matching circuits are illustrated.

Fig. 4 compares the simulated and measured circuit performances of the designed LNAs. As can be seen in Fig. 4 (a), the 2.4 GHz LNA obtained by the GA optimization
satisfies the desired design targets very well. Although there is a slight discrepancy between the measurement and simulation (which may be stemmed from the tolerance of the lumped capacitors and the circuit fabrication), the input and output return loss \( S_{11} \) and \( S_{22} \) are still better than 10 dB over the frequency bands of 2.2 to 2.6 GHz. In addition, the small signal power gain is higher than 25 dB from 2.0 to 2.5 GHz, and the noise figure is about 2 dB around 2.4 GHz. Finally, Fig. 4 (b) shows the performances for the 5.2 GHz LNA. Good results are again observed. The input and output return loss are both better than 10 dB from 5.0 the 5.3 GHz. Meanwhile, the measured power gain has the peak value of 12.7 dB at 5.2 GHz and the noise figure is about 2.0 dB.

IV. CONCLUSION

The GAs have been successfully applied to the LNA optimization designs. By the proposed optimization algorithms, two LNAs for 2.4 and 5.2 GHz WLAN systems have been designed and implemented. It has been found that the optimization can be efficiently carried out by the GAs. The computing time of the optimization is about 3 minutes for both the tested examples. In addition, the simulated and measured results have shown that the obtained LNA designs well satisfy the desired design targets, which validate the capability of GAs in the LNA designs.

REFERENCES