Towards a Tool-Box for the Synthesis of Integrated Radio Front-ends

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ABSTRACT

This paper presents design tools and optimization techniques useful for the design of radio front-ends consisting of integrated active and passive parts. The advantage of hybrid active-passive design technique is demonstrated by highlighting the results of a slot matched transistor amplifier. An efficient design of similar hybrid active-passive circuits needs computationally efficient design tools for the active and passive components interfaced using powerful optimisation tools. Synthesis of aperture microstrip antennas modeled using transmission line models and interfaced with Genetic Algorithm optimization tool will be presented as a part of this objective.

INTRODUCTION

The design tools for microwave and millimeter wave (RF) integrated circuits suffer from the large gap existing between passive and active RF design methodologies. On the other hand it has been proven that there are many advantages in integrating hybrid active-passive design techniques. One example where large advantage in system parameters have been achieved by bringing together passive RF parts and active RF circuits together is active antenna design [1]. Apart from the advantage of achieving small size of the overall system active antennas has several attractive features such as superior noise figure characteristics, large system bandwidth and decreased mutual coupling between the antenna elements. Another example where the characteristic of active circuits is improved by incorporating computationally complex passive RF devices is the slot-matched amplifier. It has been shown in [2] that the slot-matched amplifier has improved gain, bandwidth and noise figure characteristics compared to traditional stub matched amplifiers. In the integration of antennas with active devices microstrip antennas are beneficial to use since the transmission line models are accurate and computationally efficient for these types of antennas [3][4].

To develop a synthesis tool for the antennas we apply an evolutionary algorithm namely the Genetic-Algorithm [5] together with the transmission line model for the microstrip antenna. Although the method presented here is used only for synthesizing of passive antennas, a similar approach is planned in the future to synthesis active antennas by coupling the optimization-antenna design tool already developed to an active circuit simulator.

HYBRID ACTIVE-PASSIVE RF DESIGNS

This section considers two different hybrid active-passive design techniques namely an active antenna and a slot matched microwave amplifier. The block diagram for the active antenna simulator is shown in Fig. 1. The design involves active and passive RF components and the antenna itself. All the individual blocks are coupled together using an optimization tool.

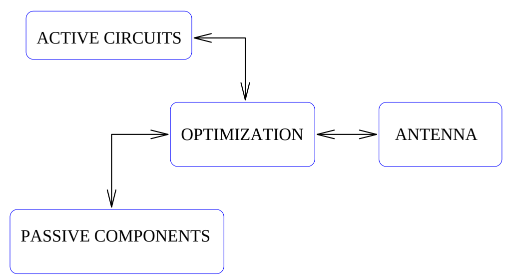

Fig. 1. Block diagram of the active antenna simulator.

One of the significant advantages of involving all the RF building blocks in the design phase is the possibility of tradeoffs between different parts in achieving e.g. the total gain in the antenna near system. This points to the need for a powerful optimization tool and analytical tools for each of the blocks. Thus the computational efficiency involved in the simulation of the overall system is proportional to the computational complexity of the individual blocks. In this context traditional fullwave electromagnetic tools for passive RF components such as Finite Element Methods (FEM), Method of Moments (MoM) and Finite different time domain methods are inferior since they suffer from large computational complexity. Models of different passive components derived by neural network methods and fullwave methods may be an alternative. However the training procedures for complex passive electromagnetic components using neural network can be difficult. In the next section the interface between the optimization blocks (based on Genetic Algorithms) and an efficient simulation method based on the transmission line model for aperture coupled microstrip antennas will be presented. Thus, two blocks seen in Fig.1 namely the antenna and the optimization blocks are here merged together. In the future work the active RF simulator will be interfaced with the antenna and the optimization tool opening the way for the simulation of the complete active antenna. An important hybrid active-passive design to be considered is the microwave transistor amplifier, see Fig.2.

Fig. 2. A microwave amplifier where the input and output match sections is shown separately.

Traditionally, the input and output matching circuits for a hybrid microwave amplifier are based on transmission line stub matching technique. Although the input and output matching circuits using stubs are easy to design, they need a large substrate space, which might be unbearable for some applications where low permitivity substrates are preferred. In the next section we present the results on using slot-matching [2] technique, which can be considered as an alternative technique to stub matching for designing microwave amplifiers. It will be demonstrated that benefits in the operating characteristics of the amplifier, such as e.g. improved bandwidth, can be achieved using slot matching. A computationally efficient technique has been developed for the analysis of slots in the ground plane of a transmission line. This technique can be integrated in an active circuit simulator [6].

Genetic Algorithms for optimization

Genetic Algorithms (GA) are robust, stochastic search methods based on the concepts of natural selection and evolution. GA optimizers can efficiently locate global maximum or minimum for problems with many parameters and objective functions in a near optimal manner. One of the most significant features of the GAs is the coding of the function parameters and its ability to operate on a group of trial solutions in parallel. The GAs are able to handle discrete, continues, discontinues and mixed functional domains. One of the drawbacks of GAs are their slow convergence, however by the increasing computational power and parallel processing in modern computers GAs can be adapted to solve any complex problem. The concept for GAs is shown in the block diagram in Fig. 3. It performs five basic tasks: (i) encode the solution parameters in the form of chromosomes, (ii) initialize a starting point population, (iii) evaluate and assign fitness values to the individuals in the population, (iv) perform reproduction through the fitness weighted selection of the individuals from the population and (v) perform recombination and mutation to produce the members of the next generation.

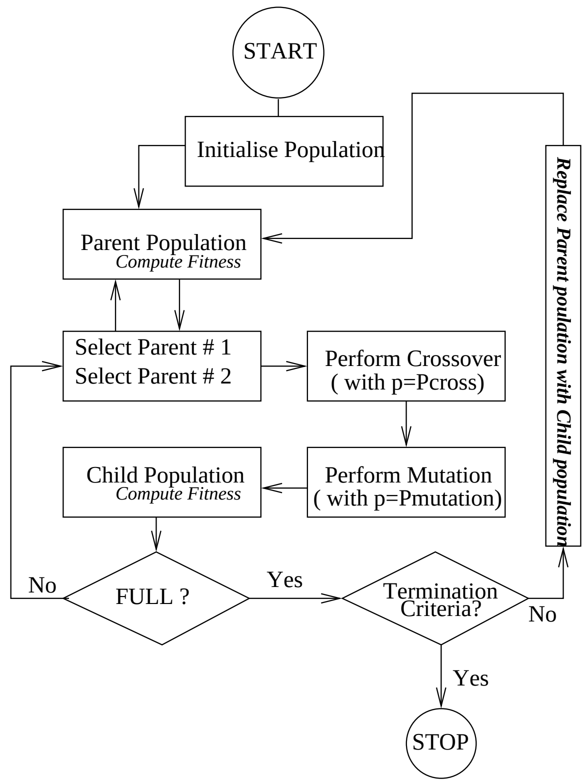

Fig. 3. Block diagram of the Genetic Algorithm

Antenna Synthesis using Genetic Algorithm

The synthesis tool developed consists of two parts. The first part is the analysis tool for the antenna, which consists of the computationally efficient transmission line model. The antennas considered are single layered and aperture coupled microstrip antennas. The analysis tool, which is written in C++, is interfaced with the Genetic Algorithm optimization tool which is also written in C++. Since C++ is used as the programming language for both the analysis and the synthesis, all the advantages of the object-oriented language are retained in the developed antenna synthesis tool. The most important part of the active antenna simulator described in Fig. 1 can thus be successfully completed, namely the antenna, the optimizer and the interface (between the antenna and the optimizer). Therefore the method proposed can be easily extended to active circuits-antenna hybrid designs such as active antennas.

RESULTS

Slot matched microwave amplifier

The layout of slot-matched microwave transistor amplifier is shown in Fig. 4. The slot-matched amplifier [2] needs only half the substrate space compared to the traditional stub matched amplifier, since the ground plane of the substrate has been efficiently used for housing the slots. Thus, the computationally complex slots can here be efficiently used as matching tools in a hybrid active-passive design.

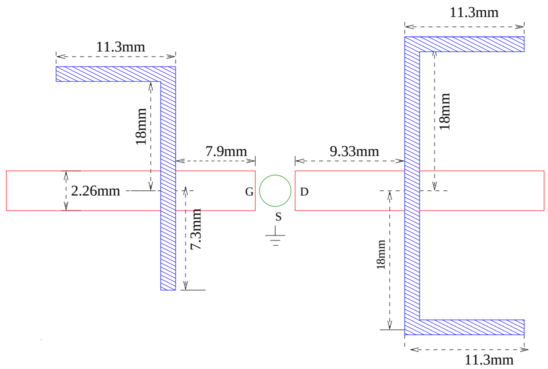

Fig. 4. Slot matched microwave transistor amplifier.

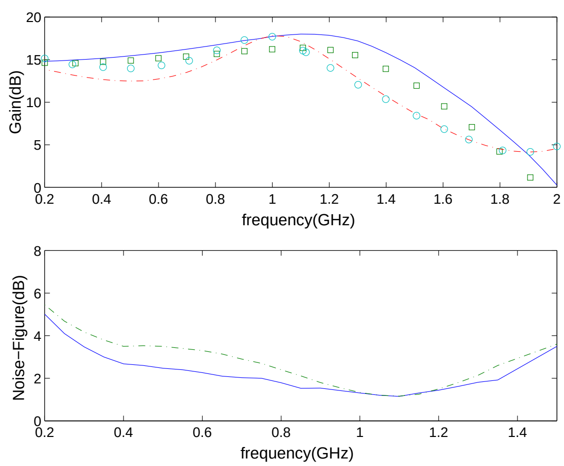

Fig. 5. Gain and noise figure characteristics of a slot matched microwave transistor amplifier.

In Fig.5 is shown the gain and noise figure characteristics of the slot matched amplifier compared with the traditional transmission line stub matched amplifier. It can be seen that both the gain and noise figure characteristics of the slot-matched amplifier has been improved compared to stub matched one.

Synthesis of a millimeter wave silicon micromachined antenna using Genetic Algorithm and Transmission line models

Silicon micromachining can be used for suppressing substrate modes for planar structures and thereby increasing the bandwidth of e.g. patch antennas. In Fig.6 is shows the cross-section of a millimeter wave Si micromachined antenna. The antenna consists of two silicon wafers of which one of them has a micromachined cavity. The lower wafer contains the microstripline feed of the antenna. The feed is coupled to the patch radiator via an H-shaped slot. More details about implementation and the extended transmission line analysis of the structure are presented in ref. [6].

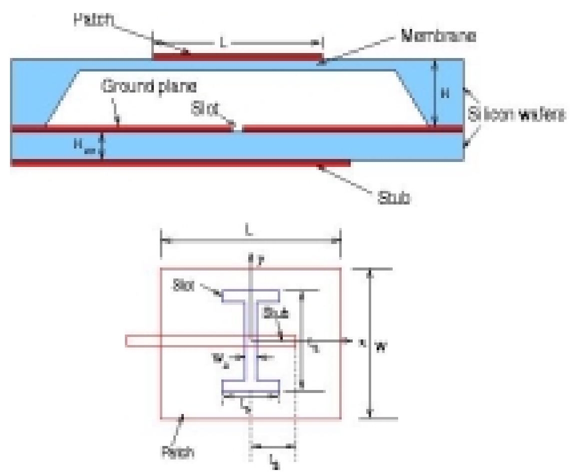

Fig. 6. Side and top view of a silicon micromachined H-slot coupled patch antenna.

The parameters considered for the synthesis of the antenna are the width (W), the length (L), the stub length (L_s), and the slot dimensions (L_a and L_h), see Fig.6. The following parameters of the antenna are given: the frequency of tuning=55GHz, the thickness of membrane=50µm, the thickness of the patch wafer and the microstrip wafer which are 254µm and 100µm respectively. Thus there are four unknown parameters to be synthesized. The object function to be maximized is the antenna return loss.

The transmission line model with the Genetic algorithm is used for the synthesis of the antenna. For a uniform crossover strategy (see Fig. 3), two versions of Genetic Algorithms are used simultaneously namely with elitism and with out elitism. If elitism is used then the best parent is always retained in the child population irrespective of the fitness of the child that it replaces. It can be seen that the probability that the best child is lost using this method is $1/N_{pop}$, where N_{pop} is the number of citizens in each population. The number of citizens in

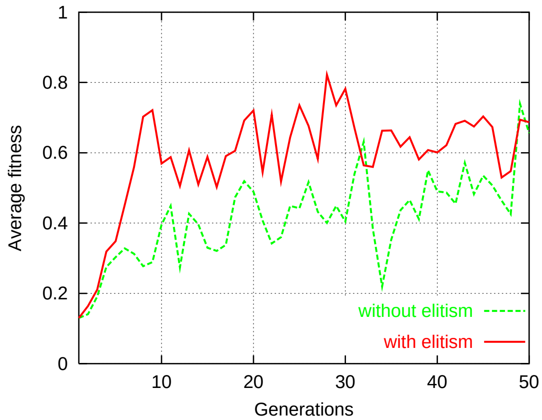

Fig. 7. Variation of the average fitness of the population with respect to the generation number.

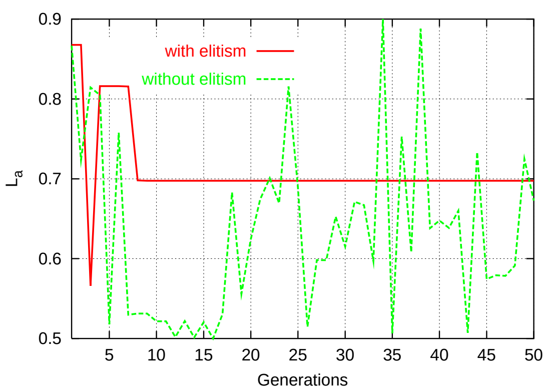

Fig.8. Variation in the slot parameter L_a as a function of the generation number, with and without elitism.

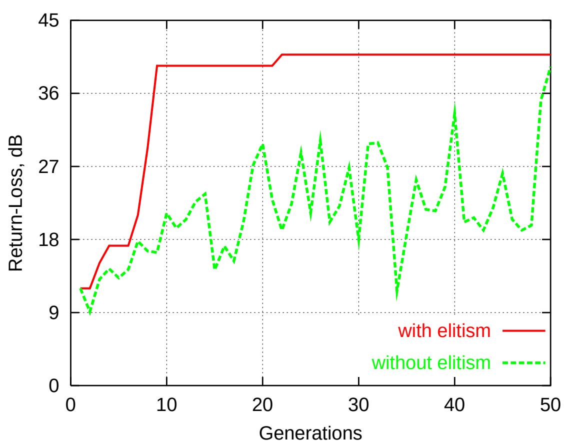

Fig. 9. Return Loss characteristics of the synthesized antenna as a function of the generation number.

each population is selected to be 16. A binary coding of 64 bits is used for encoding the parameters in the GA. In Fig.7 is shown the average fitness of the population as a function of the generation number in the GA being run. It can be seen from the simulations that the average fitness of the population is increasing with each new generation.

Fig.8 shows the variation of H-slot parameter L_a as a function of each new generation. It can be seen that for the GA run with elitism the slot parameter is stabilized around 0.7mm. Fig.9 shows the return loss characteristic for the synthesized antenna. It can be seen that antenna return loss is acceptable after around 10 generations of the GA, with elitism. The return loss characteristic of the antenna is smaller when the GA is run without elitism. It should be noted that the GA without elitism is best for producing a diverse population. However for the case of the synthesis of the millimeterwave antenna considered here the GA with elitism is found to better.

The antenna parameters which was synthesised to have maximum return loss at 55GHz was after the GA run, with elitism, found to be: W=L=1683µm, L_a=697.5µm, L_h=313.7µm and L_s=305.2µm.

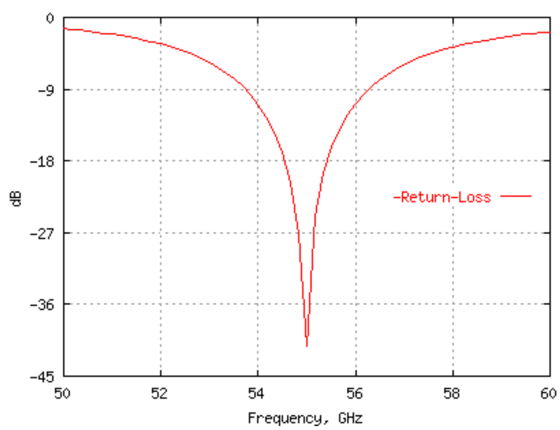

Fig.10. Return loss characteristic of the synthesised antenna as a function of frequency.

Fig.10 shows the return loss characteristics of the micomachined antenna as a function of frequency. It can be seen that the antenna is tuned exactly at the right frequency, being 55GHz.

CONCLUSIONS

From the design of a slot matched transistor amplifier it was concluded that hybrid passive-active RF designs need powerful optimization tools interfaced with computationally efficient electromagnetic tools. Designs of active antennas, which is another important hybrid active-passive design area has been examined. Towards the design of active antenna, the computationally efficient transmission line model has been integrated with the powerful Genetic Algorithm. The synthesis tool has been used to design a millimeterwave micromachined patch antenna. These results encourage the work on bringing active circuit analysis into the antenna-optimization toolbox paving the way for the design of active antenna.

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