Multi-band Handset Antenna Design Using A Genetic Algorithm

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Abstract

With the rapid growth of mobile communications and antenna market demands, the need for a multi-band, simple geometry, low cost and small size handset antenna design became a vital necessity. In the constricted place in a mobile handset the main aim will be to design a multi-band handset antenna which must effectively operates on at least three wave bands with high efficiency and also be free from unwanted spurious radiation illuminating the user’s head (low SAR value). To design such a complex multi-band antenna, a novel way is required rather than using the empirical method. The search for best design geometry requires an optimisation method, and one promising method is the Genetic Algorithm (GA). A GA will be presented through this paper, and its capabilities will be showed through a design example of simple dipole and a dual-band antenna handset primary design. It is intended that the dual-band antenna is a development step towards a multi-band design with a low manufacturing cost.

1 Introduction

Antennas for forthcoming generations of mobile handsets will facilitate voice, data and multimedia applications through single antenna designs operate at the different available mobile communications bands. This will facilitate both international roaming and connectivity to local devices. Furthermore the antenna must remain small, reasonably efficient and optimised for low SAR. These specifications add to the complexity of the design.

Existing designs of multi-band antennas have evolved empirically using prototypes developed with innovative ideas and intuitive trials. Some shortfalls are that it is only adequate for simple geometries, prototype manufacturing is relatively slow compared to simulation iterations and the design strategies are subject to error in human judgement. To achieve increasingly complex designs, a systematic and accurate optimisation technique is required to provide solutions. This paper reports on a Genetic Algorithm (GA) optimisation technique written in Visual Basic to control CST’s MICROWAVE STUDIO® (Computer Simulation Technology) as the simulation tool. GAs are search algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human research [1], [2]. In every generation, a new set of artificial creatures (chromosomes) is created using random features of the preceding best-fit generations. They efficiently exploit historical information to speculate on new search points with expected improved performance. In this paper the GA has been applied to two different antennas: a simple dipole that resonates at 0.78GHz and a dual-band patch antenna suitable for personal communication handsets at GSM900/DCS1800. It is intended that the dual-band antenna is a development step towards a multi-band design with a low manufacturing cost.

2 Genetic Algorithm Process

The GA uses an evaluation function to optimise the desired performance requirements, where an objective value is assigned to each chromosome from the produced generations and used to determine the fitness of the resulting model. The whole optimisation process is shown step by step in Fig 1. (Step 1) the chromosome is the basic block of the GA as it carries all the essential information about a particular geometry. There are two different ways of encoding the parameters: real value representation and binary format [2]. In this case, real value representation was used to create the chromosome structure in a one-dimensional array. Labelled the seed chromosome, it is used to formulate a population of random chromosomes (parents) (step 2) for simulation in CST MICROWAVE STUDIO® (step 3). The resulting $S_{11}$ for each geometry is evaluated (step 4) by calculating the difference between the individual $S_{11}$ and the target $S_{11}$. The best fit chromosome will have the highest numerical objective value. If the GA has converged on the target, then the user can terminate it (step 5). Otherwise the reproduction process continues with (step 6). The selection opera-
tion determines the number of trials that a particular chromosome (parent) is chosen for reproduction from the created population. A Roulette Wheel method is used for selection from the produced population of chromosomes based on probability and the performance of the chromosome [1]. The crossover operation (step 7) is the basic operator for producing new generation of chromosomes (children) from the selected chromosomes (parents). Like their counterparts in nature, the new chromosomes have some parts of both parent’s genetic material. To guarantee new creation and to avoid focusing on local minima, the mutation operation (step 8) is used. The new chromosomes (children) are then simulated (step 9) before being evaluated (step 10). The reinsertion operation (step 11) decides which of the new chromosomes remain in the population and which are replaced to keep the population size fixed during each generation in order to produce a new population of chromosomes. Finally, the new population will be evaluated (step 4) and assessed against the target. The GA keeps looping by creating new generations until it converges to an optimum solution.

3 Application Examples

3.1 GA Optimisation of a Dipole

A simple dipole with a resonance at \( f = 0.78 \text{GHz} \) and \( \text{BW}_{(-10\text{dB})} = 12.6\% \) was submitted to the GA Fig 3. It can be noted from Fig 2 that the dipole parameters are: outer radius, inner radius, length and air gap. The seed geometry chromosome of a dipole in millimetres is: \([2.999\ 0.000\ 1666.650\ 8.332]\). The target \( S_{11} \) is to resonate at \( f = 0.9\text{GHz} \) and \( \text{BW}_{(-10\text{dB})} = 13.6\% \) as it depicted in Fig 3. Only two parameters in the seed chromosome have been varied for optimisation, the dipole outer radius and the length. The GA converged with the target at generation 107, as it can be seen from Fig 4. A \( \text{BW}_{(-10\text{dB})} = 14.4\% \) at \( f = 0.9\text{GHz} \) has been achieved and the associated chromosome was: \([3.838\ 0.000\ 124.495\ 8.332]\) Fig 3.

![Fig 1 Genetic Algorithm Flowchart](image1)

![Fig 2 Dipole seed geometry modelled in CST MICROWAVE STUDIO®](image2)
3.2 GA Optimisation of a Dual-band Antenna

A dual-band patch antenna was also submitted to the GA. The antenna design is similar to a PIFA antenna design [3], [4]. The PIFA can be implemented in a small space and embedded in a handset. The ability to incorporate dual band or multi-band performance further enhances the merit of the PIFAs for future application. The initial design that the GA started with, consists of a rectangular patch of 6mm height above the ground plane, a shorting wall close to one of the patch corners and a coaxial cable that feeds the antenna on the upper edge of the patch Fig 5. The main parameters that describe the antenna geometry are the slots dimensions (Slot_1, Slot_2, Slot_3 and Slot_4), where each slot has four dimensions (Slot Width Start, Slot Width End, Slot Length Start and Slot Length End), probe feed position and the short wall width. Due to the complex shape the chromosome consisted of 18 parameters. The seed geometry $S_{11}$ is shown in Fig 6, with a resonance $f_1 = 0.857GHz$, $\text{BW}_{(-5\text{dB})} = 52\text{MHz}$ and $f_2 = 1.944GHz$, $\text{BW}_{(-5\text{dB})} = 114.4 \text{MHz}$. The target of optimisation was to make this initial design to operate at 920MHz, $\text{BW} = 80\text{MHz}$ and 1795MHz, $\text{BW} = 170\text{MHz}$ as shown by the target limits in Fig 6. Four parameters have been selected for optimisation from the 18 parameters: Slot_1 Width Start, Slot_2 Width Start, Slot_3 Width Start and Slot_4 Width Start. By generation 33 as it shown in Fig 7 the GA started to converge toward a solution. The $S_{11}$ for the chromosome at generation 33 is shown in Fig 6, where it can be noted that there are two bands, one resonates at $f_1 = 945 \text{MHz}$, $\text{BW}_{(-5\text{dB})} = 60\text{MHz}$ and the other resonate sat at $f_2 = 1.811\text{GHz}$, $\text{BW}_{(-5\text{dB})} = 105.4\text{MHz}$.

![Fig 3 S11 for the dipole seed geometry, target and the optimum generation (G107)](image1)

![Fig 4 Best objective value per generation for a dipole optimisation](image2)

![Fig 5 Dual-band antenna seed geometry modelled in CST MICROWAVE STUDIO®](image3)

![Fig 6 S11 for the dual-band seed geometry, target limits and the optimum by generation 33](image4)
It is anticipated that further runs of the GA or optimisation of other parameters will improve the results even more.

![Fig 7 Best objective value per generation for a dual-band antenna](image)

### 4 Conclusion

For the dipole optimisation, the GA set the resonance on target and the $BW_{(\text{LDM})}$ was improved by 1.8% after 107 generations. On the other hand, the dual-band antenna starts to converge with target by generation 33. Where the lower band needed to be shifted 25MHz and to improve the bandwidth by 20MHz. The upper band needed to be shifted 16MHz and to improve the BW by 64.6MHz.

One of the GA advantages is its ability to assess quickly whether the selected parameters are appropriate for optimisation. Another advantage is that using this method will guarantee that the simulation machines will be employed 24 hours a day. The principle factors controlling GA convergence are the number of variables per chromosome, the number of chromosomes per population and the simulation time. The GA can be improved by processing multiple subpopulations instead of a single population using high–level genetic operator functions and a routine for exchanging individuals between subpopulations. Finally, once a novel design for the dual band antenna is produced, it will be modified and re-optimised to produce a multi-band handset design.

### 5 Literature


