Genetic Algorithms for the Design of THz Components

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***Abstract*—A genetic algorithm, coupled to a finite difference time domain simulator, is presented for the optimisation of passive THz devices. A broadband THz micropatch antenna has been designed using this system and tested using a vector network analyser in the frequency range 0.75 THz to 1.10 THz.**

I. INTRODUCTION

The growth of data usage each year causes a greater demand for increased transfer rate and bandwidth. This is driving standardisation of the spectrum at ever higher frequencies, increasing the number of regions available for high bandwidth communication. A topical region of interest is the so-called THz gap, ranging roughly from a few hundred GHz to a few THz. The THz frequency range poses unique challenges, which would benefit from bespoke optimisation tools. Genetic algorithms have been successful at developing new devices and antennas at lower frequencies [1]. This work extends this approach to the THz region. A genetic algorithm applicable to a host of devices, such as THz antennas, waveguides and impedance matching networks is presented.

II. METHOD

A genetic algorithm is a metaheuristic computational technique used to find sufficiently optimal solutions to problems that cannot be solved analytically. An initial population of individuals is simulated to determine key characteristics. Performance in the simulations is analysed by a fitness test, which combines these characteristics into a ranking. The fittest individuals are used to create the next generation (reproduce) using the genetic operators of crossover and mutation. This is an iterative process where each generation is used as the parents for the next. The algorithm is terminated at a set fitness level, number of generations, or after maximum fitness stagnation [2]. The genetic algorithm presented here has been designed in such a way as to be easily adaptable to a variety of problems. The basis of the algorithm is shown in figure 1.

Before the algorithm is initialised, all files are automatically produced via Matlab script. The number and the size of generations is varied based on parameters such as the number of constraints, the required convergence time and the disk space available. The initial generation is a 2D or 3D array describing the object of interest. This could be an antenna, waveguide or other THz device, but must be describable in cubic elements [3].

Lucifer [4], a Durham-developed FDTD (finite difference time domain) simulator is the primary simulation tool used in this work. Matlab has also been used to simulate both impedance matching networks and antennas. Matlab's Antenna Toolbox does have frequency limitations, but these can be circumvented for simple designs. Matlab and Lucifer have been used as they both provide numerical outputs (images and diagrams being unsuitable here due to the time required for additional analysis).

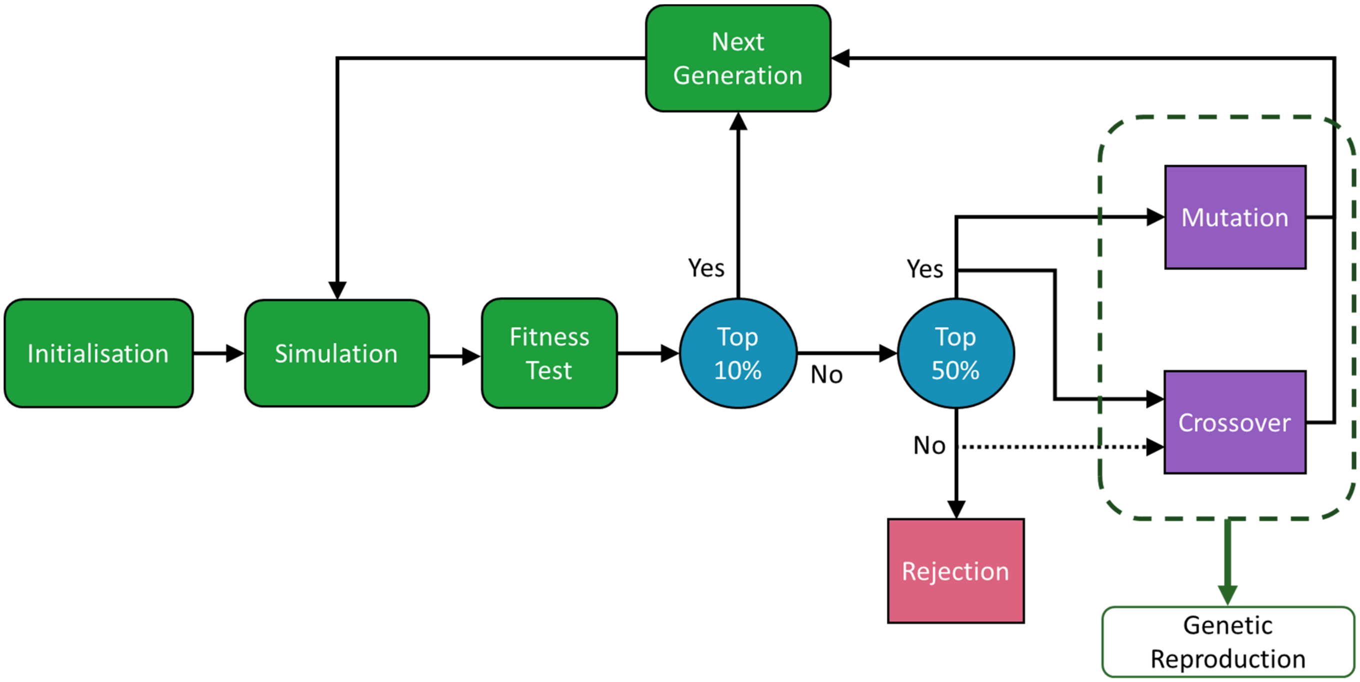

Fig. 1. A simplified diagram of the genetic algorithm used to design all the electromagnetic devices in this project.

Simulation results are the input to the fitness test. Single-number outputs from the simulation could be used directly in lieu of the fitness test. However, most simulations will provide (for example) a time series output of the simulation at a point in space, the simulated array at a point in time, or a list of parameters of interest. The fitness test is the only major component of the algorithm that needs to be specifically adapted to the use case. The reproductive stages are entirely self-adapting. The fitness test provides one score for each simulated individual, combining weighted simulation outputs. For instance, weighting antenna gain at the frequency of interest against that across the remaining spectrum.

The genetic reproduction algorithm only requires the cubic element descriptions (genome sequences) of the current generation and their respective fitness scores. The top-performing 10% are carried over to ensure no generation will be worse than the previous. The top-performing 50% undergo mutation and crossover algorithms and their offspring form most of the next generation. However, a small number of individuals with lower fitness scores are kept to stop premature convergence, as investigated by Fraser [5]. Pincus [6] notes that this method of "soft" selection reduces stagnation around peaks, leading to quicker rates of escaping local minima. The rate of mutation is inversely proportional to the spread of fitness scores to ensure that when the algorithm starts to converge, greater effort is put into finding genetically radical solutions. The mutation and crossover algorithms are completely applicable to any use case.

III. VERIFICATION

An important aspect of this work is verifying the simulated results seen through both Lucifer and Matlab. Among other use cases, antennas optimised for power collection between 0.75 THz and 1.10 THz, given a fixed load impedance, were designed by the algorithm. The fittest antenna candidate has been fabricated and tested using a THz VNA (vector network analyser) at these frequencies. The manufactured antenna can be seen in figure 2.

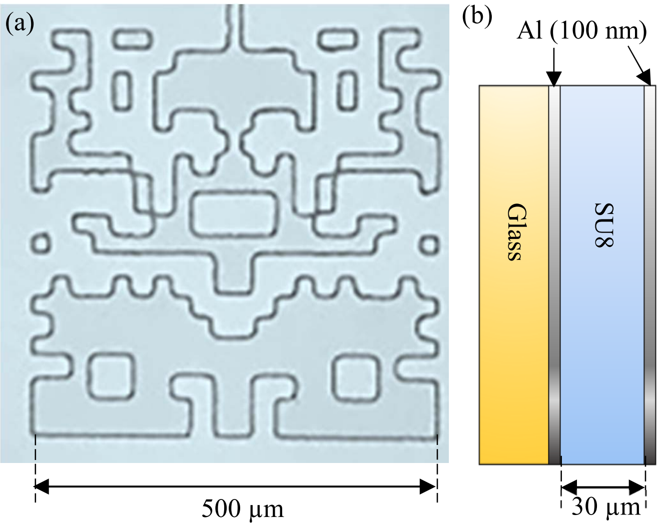

Fig. 2. An example of a genetically designed antenna fabricated for testing at THz frequencies. The design is based on a microstrip antenna with SU8 substrate. (a) shows the manufactured pattern, which matches the best candidate design (b) shows a cross-sectional view of the antenna.

The antenna shown in figure 2 was produced in the Durham University clean room. The algorithm specifies a minimum feature size to ensure ease of manufacture. Both metal layers were aluminium, sputter coated to a thickness of 100 nm, with the patterned layer produced through lithography and wet etching. A 30 μm layer of SU8 was spin coated between these. SU8 was chosen as a substrate because it has low dielectric losses at THz frequencies [7] and its properties and spin coating times are well-documented.

The test set-up is shown in figure 3. The VNA is attached to two frequency extenders. The transmitted THz signal is focused on an antenna. The signal passes through a 20 μm feed line to a second, identical, antenna, from which it is retransmitted to the other extender head. There is a variation in feed lengths between antenna pairs, so that the feed loss can be determined and isolated from antenna characterisation. These measurements are ongoing in the Durham THz laboratory.

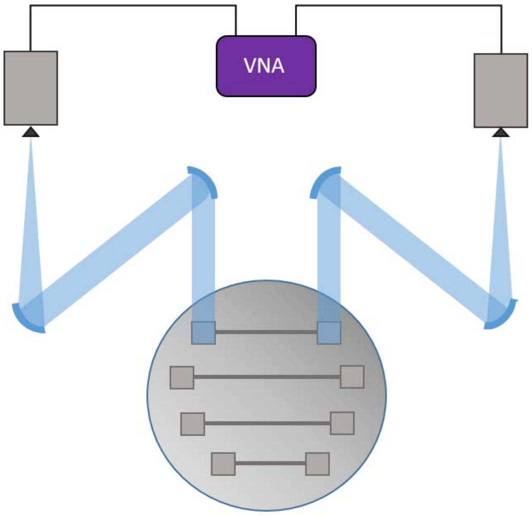

Fig. 3. Test configuration for the antenna shown in figure 2. Instances of the antenna are represented as plain patches. A VNA is used with frequency extender heads to provide a 0.75 THz to 1.10 THz test bed.

IV. SUMMARY

An adaptable genetic algorithm has been presented and used to design a variety of passive THz devices, including antennas. A sample of these antennas has been produced to scale. A test bed has been designed for their characterisation and testing is currently being completed.

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