

Electromagnetic Multilayer Absorber Design with Quantum Selection Optimization

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Abstract – Electromagnetic absorbers are applied in multiple applications and therefore, are subjected to different constraints. In this paper the design of an electromagnetic absorber is tackled by a couple of hybrid quantum-classical optimization algorithms that overpass the performance of a generic genetic algorithm usually applied in these scenarios.

Index Terms—Electromagnetic absorbers, evolutionary algorithm, quantum computing

I. INTRODUCTION

The design of electromagnetic (EM) absorbers is a common problem in electromagnetic compatibility due to their long list of applications ranging from stealth technology to instrumentation. Their design is plagued with tradeoffs specially in absorption vs thickness. For this reason, the application of optimization algorithms (OA) is common practice when designing them [1].

In general, evolutionary OAs are used due to their advantages when fighting against local minima, and due to the simplicity for the creation of fitness functions. In the last years, the emergence of quantum computing became clear, making the design of hybrid quantum-classical OA a necessity [2].

In this paper, a hybrid quantum-classical OA presented in section II is applied for the design of multilayer electromagnetic absorber shown in section III. Finally, the results of these designs are presented in section IV with a final conclusion.

II. OPTIMIZATION ALGORITHM OVERVIEW

The optimization algorithms selected for the design of the absorber are the genetic algorithm with quantum selection which was first presented in [3] using heuristic crossover and uniform mutation (referred to as GAQS-HCO), and its improved version, presented in [4] using simulated binary crossover and gaussian mutation (referred to as GAQS-SBX). The overall operation of this algorithm is described in the flowchart presented in Fig. 1.

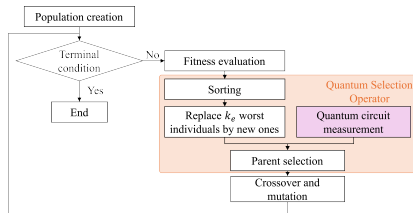


Fig. 1. Flowchart of the genetic algorithm with quantum selection

The quantum circuit (QC) measured for the parent selection process is presented in Fig. 2. It is an amplitude amplification QC that consists of three sections, first an initialization section that creates a uniform superposition of all states. Second, an

oracle, in this case a 6-input Toffoli gate which signals that the desired state is the one assigned to the individual with best fitness. Finally, a Grover Diffusion Operator (GDO) that modifies the states measurement probability based on the oracle information to boost the possibility of measuring the desired state.

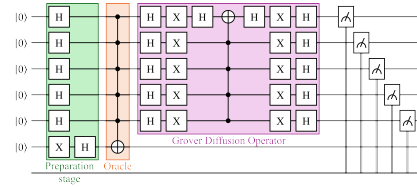


Fig. 2. Quantum circuit used for GAQS.

In order to analyze these algorithms' performance in the design of the absorber that is presented in section III, a reference generic genetic algorithm (GA) is used with tournament selection, heuristic crossover and uniform mutation. The parameters of each one of the evolutionary algorithms are population size 32, 3% mutation rate and k_e equal to 3

III. MULTILAYER ABSORBER DESCRIPTION

The multilayer absorber considered for this application is presented in Fig. 3. It consists of four layers of different materials with different properties and thicknesses represented by ϵ_{ri} , μ_{ri} , and d_i . Where i is the layer's number.

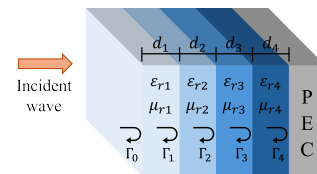


Fig. 3. Multilayer absorber schematic.

The materials chosen in this case are fictitious and assumed not to be frequency selective, their EM characteristics are presented in Table I. It is important to emphasize that this fact does not reduce the generality of the optimization procedure presented, but only reduces the computation time of the fitness

function evaluation, giving the possibility of making multiple tests to do a statistical analysis of the algorithm's behavior.

TABLE I
ELECTROMAGNETIC CHARACTERISTICS OF THE MATERIALS CONSIDERED

Layer number	Relative electric permittivity (ϵ_r)	Relative magnetic permeability (μ_r)
1	$2 - j0.1$	1
2	$3 - j0.3$	1
3	$7 - j0.4$	1
4	$10 - j0.6$	1

The fitness of each solution is evaluated based on two parameters, the mean value of the reflection coefficient in a given frequency band (2-6 GHz for this paper) and the total thickness of the absorber. As presented below, these two metrics are combined by doing a weighted sum where their significance is controlled by the parameter w_t .

$$fitness = mean(|\Gamma|_{dB})_{f_{low} \leq f \leq f_{high}} + w_t \sum d_i$$

The computation of the reflection coefficient is a classical problem of reflection and transmission of multiple interfaces that is well explained in [5]. In this paper, normal incidence is assumed, and the approximation of small $|\Gamma_n|$ is taken.

IV. RESULTS

For all simulations a MSI Prestige 15 A10SC laptop was used. The algorithms were realized using Python with Numpy, Scipy and Qiskit. For both versions of GAQS, simulations and real measurements of QC were done. The simulator used is the Aer simulator and the real measurements were done with IBM quantum processor Eagle r3. In order to do a statistical analysis of the behavior of the algorithms presented, 50 tests were done with each one consisting of 2000 generations and setting w_t to 100.

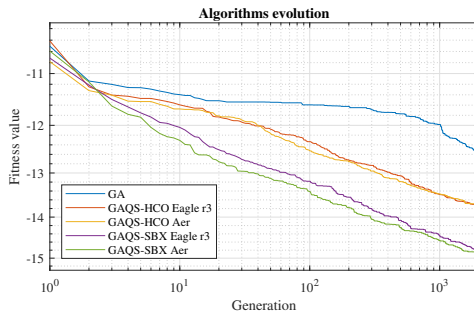


Fig. 4. Algorithms evolution.

Fig. 4 presents the evolution of the three algorithms. It is clear that both versions of GAQS overpass the performance of the reference GA. Between them, GAQS-SBX offers a better performance for this application in both convergence speed and final result. Furthermore, the QC simulation has a slight edge over the QC measurements. This difference in performance is explained by the noise levels in modern quantum computers.

In Table II the statistics of the final results are presented. The most significant aspects of these results are in the variance

TABLE II
STATISTICS OF THE FINAL RESULTS

Parameter	GA	GAQS-HCO		GAQS-SBX	
		Eagle r3	Aer	Eagle r3	Aer
Mean	-12.5526	-13.7159	-13.7159	-14.8249	-14.8481
Variance	0.8914	0.3921	0.3247	0.2249	0.2706

where there is a strong improvement of GAQS over GA and similarity between QC simulations and real measurements.

Finally, in Fig. 5 the spectral behavior of the absorber is presented, the final thicknesses of the layers are 6.04, 2.99, 2.46, and 22.92 mm for a total thickness of 34.4 mm.

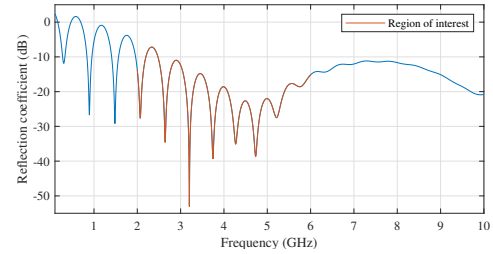


Fig. 5. Reflection coefficient of the best result obtained.

V. CONCLUSION

The hybrid quantum-classical optimization algorithm GAQS with both HCO and SBX was capable of handling the design of the multilayer absorber presented here with a performance superior to that of a reference GA, both in mean result and variance. Furthermore, the maturity of modern quantum computers is close in performance to simulators for this specific application.

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