

Synthesis of Broadband 3D AMC Ground Planes Using Genetic Programming

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Abstract— The development and use of genetic programming (GP) software to synthesize true-3D artificial magnetic conductor (AMC) ground planes is presented, with the focus on achieving a lower frequency response (particularly in the high VHF to low UHF bands), low-profile, broadband designs without the use of absorbing or magnetic materials. Metallic 3D patterns are embedded in one or more substrate layers with a PEC bottom, and the patterning in the unit cell is allowed to extend into neighboring unit cells, thus achieving a lower frequency response with much smaller unit cell size and thickness. Two designs synthesized using the developed GP software are presented with achieved bandwidths of 71.1% and 51.6% when using the $\pm 90^\circ$ reflection phase criterion.

I. INTRODUCTION

The development of metamaterial artificial magnetic conductor (AMC) ground planes for antenna applications is a very popular area of research, as they are a physical realization of the theoretical perfect magnetic conductor (PMC) which has the property of in-phase reflection ($\Gamma = 1 \angle 0^\circ$). Thus, they eliminate the frequency dependent spacing ($\lambda/4$) typically used for perfect electric conductor (PEC) ground planes and lead to low-profile designs when the antenna and ground plane are integrated [1]. Design guidelines exist for some 2D AMC structures [1], but these design procedures are typically done by trial and error which is time consuming. To accelerate and improve the design process, some use nature-inspired evolutionary optimization methods, such as genetic algorithm (GA), for single- and multi-layer 2D AMC designs [2][3]. This method, however, still requires pre-specification of topologies and then the design variables are optimized. Typically, wider bandwidth is achieved by increasing the thickness of the substrate material forming the ground plane or by using lossy and/or magnetic materials [1], which tends to be problematic for lower frequency designs. A lower frequency AMC ground plane design can be achieved without increasing the thickness by using true 3D patterning and allowing the unit cell patterning to extend into neighboring cells (explored in [3] for 2D). With the utilization of 3D space (as opposed to 2D), it is feasible to achieve the desired lower frequency response without increasing the thickness, as the longer “wire” structures necessary can be contained; however, there is limited research in designing true 3D metamaterials for use in AMC ground planes [4]. The multitude of possible 3D design topologies in 3D space, particularly when the patterning extends into neighboring unit cells, can be explored using genetic

programming (GP), which is an evolutionary computation method capable of both synthesis and optimization of topologies. GP has been successfully used in many fields of engineering but has seen only limited use in electromagnetics in the synthesis of antennas [5] and 2D AMC ground planes [6]. In this paper, the development and use of GP software to synthesize low-profile, broadband AMC ground planes in the VHF/UHF frequency range is briefly presented, and a more in depth presentation of the implementation and results is available in [7].

II. GENETIC PROGRAMMING METHODOLOGY

When GP is used to synthesize a metamaterial unit cell, the solution is represented as a computer program and running the program generates the geometry of the unit cell. An initial randomly generated population of computer programs is evolved over many generations using genetic operations until the optimal solution is reached or the design specifications are met [8]. The program architecture consists of two main branches: one for creating the substrate layer(s) and the other for creating the pattern(s). The program is represented as a tree-based data structure and uses four types of sub-trees: red, blue, pattern, and substrate. The function and terminal (inputs to the functions) sets (see Table I) are categorized as follows: arithmetic (red functions), drawing (blue terminals), creating/modifying (pattern and substrate terminals), and connecting (blue, pattern, and substrate functions). The blue sub-tree is responsible for drawing the pattern using movement, 3D rotation, and branching. For future fabrication purposes, the pattern is required to remain fully connected, but the implementation does allow for multiple patterns to be drawn. Program fitness is evaluated using a fitness function which assigns a score based on how well the design meets specifications. HFSS is used for evaluating the unit cells, and the GP software is implemented with MATLAB.

TABLE I. FUNCTION AND TERMINAL SETS

red Function Set	<i>plus2, minus2, times2, div2</i>
red Terminal Set	<i>rand with range [-1 1]</i>
blue Function Set	<i>genBranch{3-5}, iter2</i>
blue Terminal Set	<i>move1, rotpx1, rotpy1, rotpz1, rotmx1, rotmy1, rotmz1, rot{2,3}, branchOff3, endBranch0</i>
pattern Function Set	<i>genPatt{1-3}</i>
pattern Terminal Set	<i>addPatt4</i>
substrate Function Set	<i>genSub{1-3}</i>
substrate Terminal Set	<i>addSub2</i>

III. AMC GROUND PLANE DESIGN EXAMPLES

To illustrate the use of the GP software in designing lower frequency (225-450 MHz) AMC ground planes, two design examples are given. For the first design example a single substrate layer ($\epsilon_r=1.25$, $\tan \delta_e=0.005$) is specified, and the allowed range of substrate thickness is 6-13cm ($0.045-0.098\lambda_o$ or $0.050-0.109\lambda_g$ at 225 MHz). Both the phase and magnitude are included in the fitness evaluation. Fig. 1 shows the first design example, which consists of two metallic “wires” and a 12.05cm thick substrate. The reflection response to an x-polarized plane wave is shown in Fig. 2. This design has a 71.1% bandwidth covering 221.09-464.97 MHz, a minimum reflection magnitude of -5.3 dB (0.54 magnitude), and a thickness of $0.089\lambda_o$ ($\approx\lambda_o/11$) or $0.099\lambda_g$ at 221.09 MHz. The second design example allows for multiple substrate layers. The allowed thickness of each substrate layer is 10-60mm, and the maximum thickness is 60mm, which is enforced by scaling all substrate layers. The allowed dielectric constant of the substrate material is $\epsilon_r=1-15$, with $\tan \delta_e=0.01$. This time, only the phase is included in the fitness evaluation. Fig. 3 shows the second design which consists of three substrate layers and a single planar metallic “wire”. The reflection response to an x-polarized plane wave is shown in Fig. 4, and the design parameters are $t_1 = 21.5\text{mm}$, $t_2 = 24.3\text{mm}$, $t_3 = 14.2\text{mm}$, $\epsilon_{r1} = 10.26$, $\epsilon_{r2} = 10.01$, and $\epsilon_{r3} = 14.92$. The total thickness is 6.0cm, which is $0.062\lambda_o$ ($\approx\lambda_o/16$) or $0.182\lambda_g$ at 271.48 MHz. The design has a bandwidth of 51.6% (271.48-460.07 MHz), and the increase in reflection phase bandwidth is attributed to the modification of the reflection phase slope around 325 and 400 MHz. To be fair, this is an electrically thick design, but it provides a 39.4% increase in bandwidth over the substrate-only case when the metallic patterning is removed.

IV. CONCLUSION

The development and application of GP to synthesizing and optimizing true 3D AMC metamaterial ground planes has been briefly presented with promising results. Ongoing work, which will be presented at the conference, includes new initialization methods (such as Lindenmayer system or fractal patterning) and methods of increasing performance of the GP software (such as parallel evaluation of population members and hybridization of GP with a low-level optimizer).

ACKNOWLEDGEMENT

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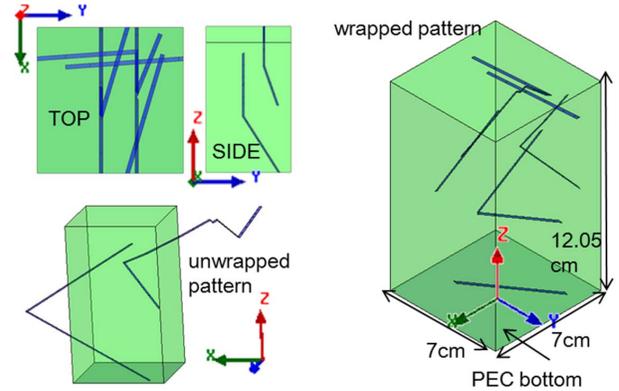


Fig. 1. Unit cell for AMC ground plane design example 1.

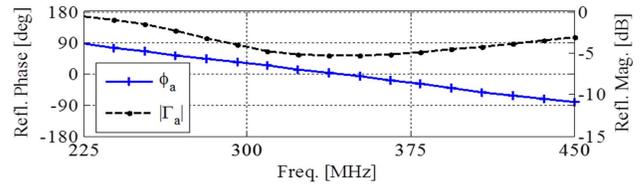


Fig. 2. Reflection response (magnitude and phase) for design example 1 with x-polarized incident plane wave.

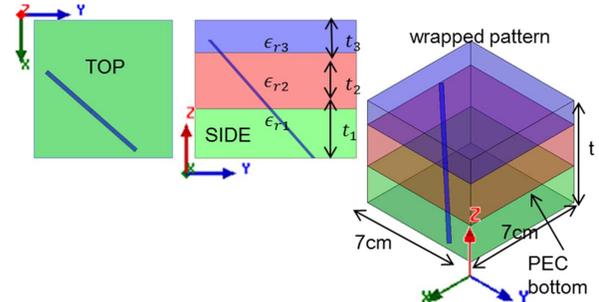


Fig. 3. Unit cell for AMC ground plane design example 2.

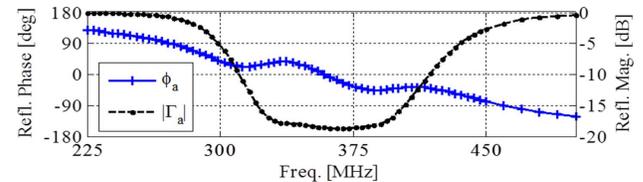


Fig. 4. Reflection response (magnitude and phase) for design example 2 with x-polarized incident plane wave.

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