2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/USNC-URSI) | 978-1-6654-9658-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/AP-S/USNC-URSI47032.2022.9886220

Using Genetic Programming to Achieve High Broadband Absorptivity Metamaterial in Compact Radar Band (1–11 GHz) without Lossy Materials

Edmond Chong(1), Scott Clemens(1), Magdy F. Iskander(1), Zhengqing Yun(1), Joseph J. Brown(2), and Matthew Nakamura(2)
(1) Hawaii Advanced Wireless Technologies Institute, University of Hawaii at Manoa, Honolulu, USA
(echong4@hawaii.edu, scottkc@hawaii.edu, magdy@hawaii.edu, zyun@hawaii.edu)
(2) Mechanical Engineering Deparment, University of Hawaii at Manoa, Honolulu, USA
(jjbrown@hawaii.edu, mtdsn@hawaii.edu)

***Abstract*—In the modern age of metamaterial absorbers (MA), many implementations are generally in the C and X microwave bands. Genetic programming (GP) software is used to generate new 3D designs for metamaterial absorbers with multilayer dielectrics to achieve high broadband absorptivity in the compact radar band (CRB) (1–11 GHz) without lossy materials. GP was previously used to create an artificial magnetic conductor (AMC) with broadband capabilities in 225–450 MHz without magnetic or absorbing materials. Utilizing the capabilities of GP to create broadband structures, the GP software is modified to create broadband MAs. Two 2D patterned structures with multilayer dielectrics were generated with above 90% absorptivity peaks around 3 and 5 GHz. The preliminary use of GP to create broadband MA structures shows excellent potential for creating a structure that broadens the whole CRB.**

I. Introduction

Metamaterials are structures created to achieve properties otherwise not found in natural materials. Metamaterial absorbers (MA) have been researched and developed for "thermophotovoltaics, photodetection, bolometry, and manipulation of mechanical resonances" [1]. Most metamaterials absorbers in the microwave regime consist of a Metal-Dielectric-Metal design, where the top layer is a patterned metallization followed by a dielectric medium followed by a metallic substrate. Many MAs developed in the microwave regime reside around the X band (8–12.5 GHz). The targeted band is the compact radar band (CRB), consisting of the L, S, C, and X bands (1–11 GHz). Little research has been conducted around the L band for broadband absorption. The designs that achieve low frequency broadband share the similarity of stacking metal sheets or resistive sheets between dielectric spacers [2][3]. The limitation of stacking multiple layers is that the structure's thickness is multiple times thicker than the targeted wavelength [4]. Common dielectric materials used in MAs are not impervious to losses, and lossy material poses a problem for these structures as heat is generated when absorbing microwaves. Single-layer dielectrics with pattern MAs have multiple absorptivity peaks across a band instead of pure broadband [5]. There is an opportunity to present a solution that addresses broadband absorption in the CRB while reducing the size of the structure while using lossless materials.

Previously, hybrid genetic programming (GP) with a low-level optimizer was used to create an artificial magnetic conductor (AMC) in the ultralow broadband performance in the 225–450 MHz without absorbing or magnetic materials utilizing 3D designs and multilayered dielectrics. The primary capability of GP is to create a structure of desired specifications that is otherwise not achieved with human expertise. With the track record of creating a low-frequency broadband AMC at 225–450 MHz, the GP software can be modified to focus on the CRB for MAs utilizing 3D structures and multilayered lossless dielectrics. GP has a proven record of providing metamaterial designs with performances exceeding those based on human expertise [6][7]. As interest for MAs grows, GP is not limited to rigid structures; flexible MAs are another avenue GP can potentially explore. In this paper, we build on prior experiences with designing broadband 3D metamaterial structures and describe the design of broadband absorbers in the CRB.

II. Genetic Programming

Broadband absorptivity in the CRB can be achieved with GP by modifying the existing GP code for AMCs and switching the focus to MAs; a design using lossless dielectric materials with broadband absorptivity is not a trivial feat. GP takes design specifications and randomly generates an initial population of designs; it is then simulated in Ansys High-Frequency Simulation Software (HFSS) and evaluated against a fitness function to see which design matches the design parameters the best. A genetic algorithm (GA) is used as a low-level optimizer to invoke mutations and crossovers in a best-performing design characteristic to create the next generation of designs. GP will keep iterating on designs with GA until the design specifications are met. The benefit of using GP with GA is that nontrivial designs perform to specifications and address the gap within the CRB. The absorptivity is measured to measure the effectiveness of a given design. Absorptivity, A is defined by

$$A = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (1)$$

where $|S_{11}|^2$ and $|S_{21}|^2$ are the reflectivity and transmissivity, respectively. The reflectivity is defined by the magnitude squared of the reflection coefficient, the S_{11} parameter, and the transmissivity is defined by the magnitude squared of the reflection coefficient, the S_{21} parameter. When there is a metal backplate to the metamaterial design, the transmissivity of the structure drops to zero, simplifying the absorptivity to

$$A = 1 - |S_{11}|^2. \quad (2)$$

A modified fitness function that minimizes the reflectivity is used to create a broadband design and high absorptivity. The fitness function will favor generated designs with broadband characteristics rather than high absorptivity at a single frequency. This modified fitness function aims to broaden the band while maintaining high absorptivity. The first step to using GP is to specify the design parameters. The desired frequency band to achieve broadband absorptivity is the CRB, 1–11 GHz. The desired materials used for the substrates are confined to those with low-loss tangents to minimize energy loss to heat. GP is not limited to 2D designs; GP can also create 3D repeatable structures. By changing the number of allowed substrates, GP can iterate on a stacked design with 3D metallization woven between layers. Fig. 1 shows an example of a 3D unit cell generated by GP with multiple substrates of different properties and the 3D metallization pattern throughout the different substrate layers.

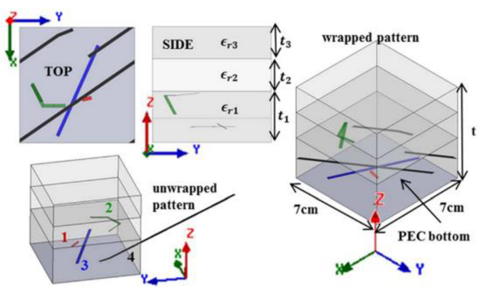

Figure 1. 3D AMC unit cell with multiple substrate and metallic wrapped pattern generated by GP [6]

III. PRELIMINARY RESULTS

To demonstrate the capabilities of the modified GP software, two preliminary 2D structure designs was generated as shown in Fig. 2(a) and Fig. 2(b). The structures have a 2D metallic pattern and multilayer dielectrics. The parameters set for these designs was 3–5 GHz for the frequency range with a cut-off frequency at 4 GHz. The dielectric constant and loss tangent range was set between ε_r= 1–10 and δ= 0.001–0.005 respectively. The structures are 5.44 mm by 5.44 mm with two different dielectric layers. In design 1, the height of the red layer is 8.69 mm, and the green layer is 28.81 mm, with a total height of 37.5 mm. The dielectric property for each layer is ε_{1Red}= 9.92, δ_{1Red}= 0.0047, and ε_{1Green}= 6.7, δ_{1reen}= 0.0048. In design 2, the height of the red layer is 14.26 mm, and the green layer is 23.24 mm, with a total height of 37.5 mm. The dielectric property for each layer is ε_{2Red}= 7.93, δ_{2Red}= 0.0049, and ε_{2Green} = 1.7, δ_{2reen} = 0.0036. As initial designs, GP generated two designs with high absorptivity peaks around 3 and 5 GHz, as shown in Fig. 2(c). Broadband is achieved due to multiple resonances overlapping and coupling. The appearance of multiple absorptivity peaks shows that GP is working towards desired broadband characteristics [8]. In both designs, slight broadband above 90% absorptivity around 5 GHz is achieved. Design 2 does not have as high absorptivity around 3 GHz; it does have increased bandwidth compared to design 1 at around 3.5 GHz. The first version of the modified GP software shows great promises to generate a structure with broadband features.

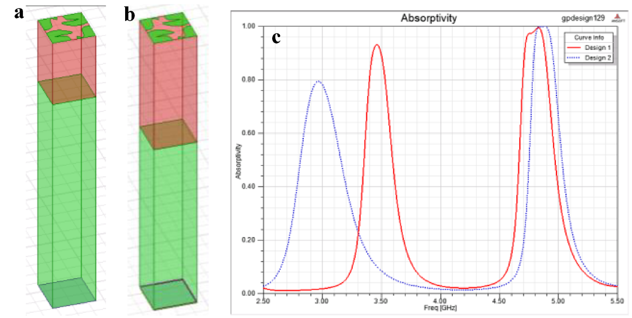

Figure 2. 2D pattern MA unit cell (a) design 1, (b) design 2 and (c) absorptivity of designs

IV. CONCLUSION

In summary, a modified version of the GP software is used to create broadband MAs utilizing 3D structures and multilayered dielectrics. Two preliminary 2D structures with multilayer dielectrics displays the potential of the modified GP to create structures with broadband capabilities. Further implementation of 3D structures with metallization within the dielectric will be explored to widen the entire CRB. The use of GP will bridge the gap that is currently present in the CRB.

REFERENCES

[1] P. Yu *et al.*, “Broadband Metamaterial Absorbers,” *Advanced Optical Materials*, vol. 7, no. 3, p. 1800995, 2019.

[2] X. Yin *et al.*, “Ultra-wideband microwave absorber by connecting multiple absorption bands of two different-sized hyperbolic metamaterial waveguide arrays,” *Sci Rep*, vol. 5, no. 1, p. 15367, Oct. 2015.

[3] C. Zhang *et al.*, “Hybrid metamaterial absorber for ultra-low and dual-broadband absorption,” *Opt. Express, OE*, vol. 29, no. 9, pp. 14078–14086, Apr. 2021.

[4] J. Jung, H. Park, J. Park, T. Chang, and J. Shin, “Broadband metamaterials and metasurfaces: a review from the perspectives of materials and devices,” *Nanophotonics*, vol. 9, no. 10, pp. 3165–3196, Sep. 2020.

[5] D. Chaurasiya, S. Ghosh, S. Bhattacharyya, A. Bhattacharya, and K. V. Srivastava, “Compact multi-band polarisation-insensitive metamaterial absorber,” *IET Microwaves, Antennas & Propagation*, vol. 10, no. 1, pp. 94–101, 2016.

[6] J. Rayno, M. F. Iskander, and N. Celik, “Synthesis of Broadband True-3D Metamaterial Artificial Magnetic Conductor Ground Planes Using Genetic Programming,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 11, pp. 5732–5744, Nov. 2014.

[7] J. Rayno, M. F. Iskander, and M. H. Kobayashi, “Hybrid Genetic Programming With Accelerating Genetic Algorithm Optimizer for 3-D Metamaterial Design,” *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1743–1746, 2016.

[8] G. C. Huang, S. Clemens, M. F. Iskander, and Z. Yun, “Analysis of GP-designed metamaterial using equivalent circuit model and Prony’s method,” Electromagnetics, vol. 41, no. 6, pp. 381–392, Aug. 2021.