Genetic Algorithm Optimized Inkjet Printed Electromagnetic Absorber on Paper Substrate

Diganta Misra[1], Rahul Pelluri[2], Vijay Kumar Verma[3], Bhargav Appasani[1] and Nisha Gupta[2]
[1]School of Electronics Engg., KIIT University, Bhubaneswar-751024, India
[2]Birla Institute of Technology, Mesra, Ranchi 835215 India
[3]Indian Space Research Organization, Bangalore- 560231, India

Abstract: Printable electronics based electromagnetic absorbers are receiving increasing attention of the electromagnetic community because of their unprecedented advantages. This paper presents the design of printable electromagnetic absorbers for the X band. The design of the absorber is optimized using the Genetic Algorithm (GA) to enhance the absorptivity and the absorption bandwidth. The design involves the placement of several square-shaped conductive ink at optimal locations on the paper substrate such that desired absorption characteristics are obtained. Simulations are carried out using the HFSS simulation software. The optimized structure offers an absorptivity of more than 90% in the X band thereby proving to be a viable solution for stealth applications.

Keywords: X-Band Absorbers, Printable Electronics, Paper Substrate, Genetic Algorithm.

I. INTRODUCTION

Electromagnetic absorbers have multitudinous applications in the field of radar engineering, microwave imaging, spectroscopy, etc. One of the important application is the design of the X-band absorbers [1-2]. Several novel contributions have been made to this field over the past few decades. It involves the use of dielectric substrates and other costly materials for realization of the absorbers. The other alternative is the use of printable electronics [3-11].

Over recent years, printable electronics has received a lot of attention as they provide us with a solution of low cost and flexible designs. The use of ecologically friendly material like paper gives us all of these advantages in addition to being renewable and having an ease of fabrication. They have gained wide popularity due to other factors such as the ease of modification, rapid production on a large scale, conformability, etc.

Inkjet technology has been used to print wearable antennas [10], RFID tags [11] and electromagnetic absorbers [12]. Inkjet printed electronic structures for absorbing the electromagnetic radiation would provide a fast and cost-effective means of fabricating the X band absorbers. M. Yoo and his colleagues proposed an absorber of with more than 90% absorbance in the frequency range 8.84-9.58 GHz [12]. In this paper an optimized structure is proposed that offers peak absorption of 99.29% for the TE polarization at 11.45 GHz with a 90% absorption bandwidth of 600 MHz. The optimization is carried out using the well-known optimization technique, the Genetic Algorithm (GA).

Use of optimization techniques for the design of structures is not a new approach. These techniques were employed for the design of bandgap structures [13] and dielectric based X band absorbers. However, these techniques have not been incorporated for designing paper-based X band absorbers. This is the unique contribution of the proposed work.

The organization of the paper is as follows: the next section gives an overview of the design of inkjet printed absorbers. In this section the procedure for generating the optimized structure design using the GA is also described. Simulation results are presented in the third section and finally the conclusions are presented in the last section.

II. DESIGN OF THE INKJET PRINTED ABSORBERS

Paper is the most widely available, organic material which provides us one of the solutions for a low cost, flexible substrate which is renewable and environment-friendly in addition to being easy to fabricate on using inkjet printing technology. Using this technology provides us with an alternative to chemically intensive fabrication techniques and have an additional advantage of fabricating complex designs seldom possible in a regular design laboratory. The dielectric constant of paper varies because of the differences in densities, texture, manufacturing techniques, etc. and thus each type of paper has its own RF characteristics. For simulation and analysis, ten layers of paper of thickness 0.25 mm each have been considered to achieve a dielectric layer thickness of 2.5 mm. For the purpose of simulation, we consider a dielectric constant of 2.95 and a loss tangent of 0.07.

The X-band absorber can be designed using the conventional method employed in several works. However, this process may become tedious and the resultant structure may not offer the desired absorption. The alternative is the use of optimization techniques for designing these absorbers [1]. The latter is not a new method of designing structures. Several researchers have successfully employed the optimization techniques for designing the structures. The optimized structure is highly unlikely to be symmetric and so cannot be used for all polarization states. In order to generate an optimized structure that fulfills the criterion of polarization insensitivity and angle insensitivity requires tremendous computational resources. Hence we limit ourselves to the design of absorbers for TE polarization and near normal

978-1-5386-8333-0/18/$31.00 ©2018 IEEE

incidence [1]. Also, the ink used for printing the absorber has to be characterized for its conductive properties [12]. However, for the purpose of simulation, the ink is considered to be perfectly conducting material.

In the HFSS tool, the design of structures and their subsequent simulation can be performed using the VB script. This script can be written in MATLAB and so, by using the GA toolbox of MATLAB, optimized structures can be generated. The steps involved in this process are: VB script is written for generating the unit cell of the absorber, which has dimensions of 'a'= 15 mm x 'b'= 15 mm and has conductive ink patches arranged on the top plane. Next, periodic boundary conditions are assigned and the reflection coefficient (s_{11}) and the transmission coefficient (s_{21}) are calculated. From the reflection and transmission coefficient, we can obtain the absorption characteristics using equation (1). Since the ground plane is conducting, there is no transmission of energy through the shielding structure and hence s_{21} can be taken to be zero. Finally, the objective function is calculated from these coefficients.

$$A(f) = 1 - |s_{11}(f)|^2 - |s_{12}(f)|^2 \tag{1}$$

The objective function that has to be evaluated by the GA depends on the bandwidth over which the structure offers the desired absorption and is given by the equation (2).

$$fitness := F_H - F_L \tag{2}$$

where F_H - F_L is bandwidth of the required absorption

The GA toolbox in the MATLAB environment codes each solution of its population in terms of binary number having a length of 100. There is a one to one mapping between the binary digits of each solution and the corresponding unit cell structure. For a binary '1' a conductive ink patch having dimensions 'c'= 1.25 mm x 'd'= 1.25 mm is placed on the paper substrate and for a binary '0' no patch is placed on the substrate. The substrate is then simulated in HFSS and the reflection coefficients are obtained. The process of obtaining the optimized unit cell structure using the GA is shown in Fig. 2.

The parameters of the GA are taken as: maximum iteration is 100, population size is 10 and the crossover rate is 0.35. The structure of the optimized unit cell obtained at the end of the simulation is shown in Fig. 3.

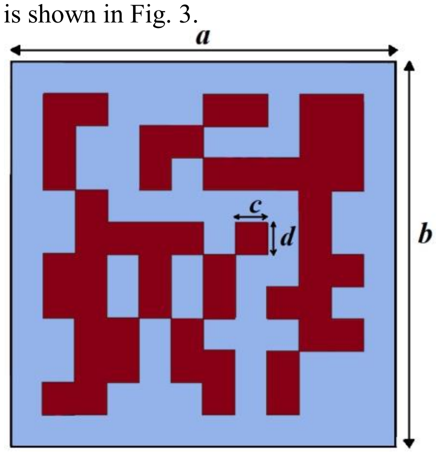
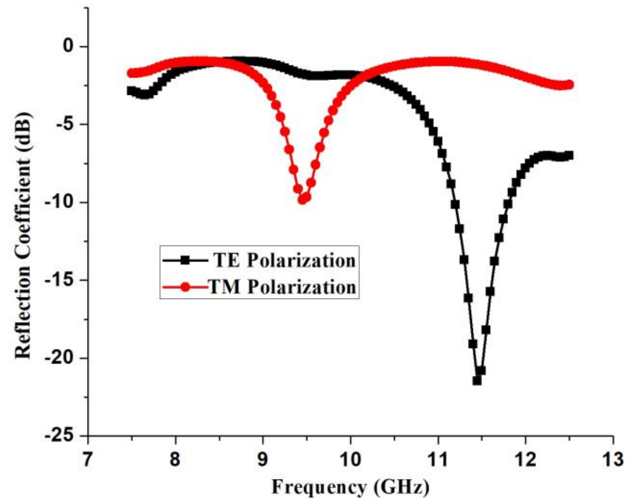


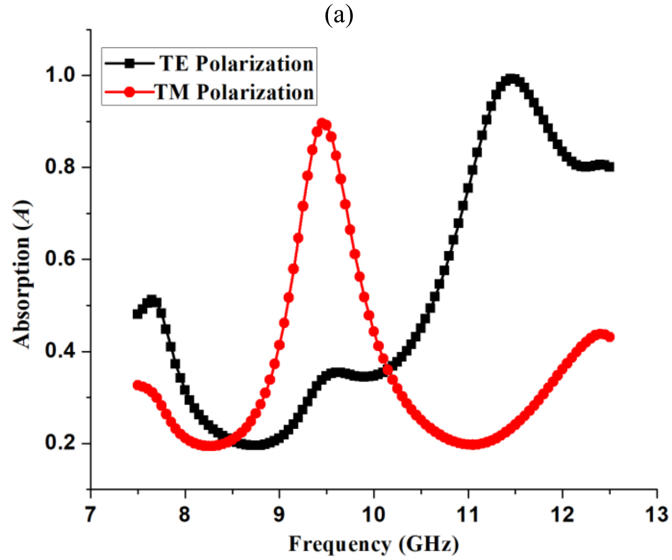
Fig. 3. Unit cell of the optimized structure

III. Results and Discussion

The absorption characteristics of the structure are shown in Fig. 4. It can be observed from the absorption characteristics that the optimized structure provides a peak absorption of 99.29% for the TE polarization at 11.45 GHz with a 90% absorption bandwidth of 600 MHz. However, the structure acts as a poor absorber of TM polarization. It offers a peak absorption of 89.6% for the TM polarization at 9.45 GHz with 85% absorption bandwidth of approximately 200 MHz. The reason behind the polarization sensitivity is that the structure was optimized for TE polarization only. However, the structure can be optimized to absorb both the polarization at the expense of increased computational resources. Next, the absorption characteristics of the optimized structure are obtained for different incident angles and are shown in Fig. 5. Even though the structure was optimized for normal incidence, it offers desirable absorption characteristics even for the 30° and 60° incident angles.

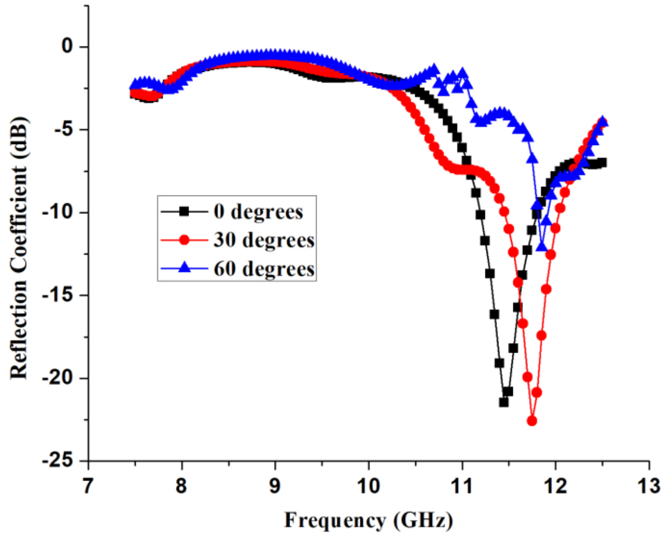


(a)

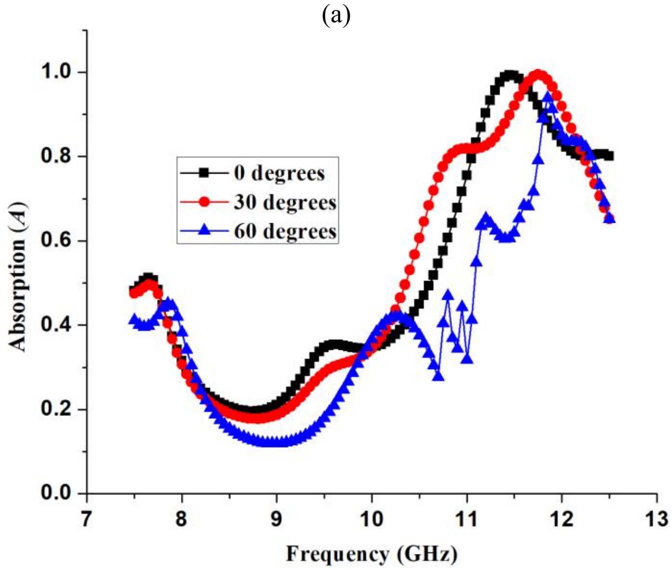


(b)

Fig. 4. (a) Reflection coefficient (b) Absorption characteristics of the optimized structure



(a)



(b)

Fig. 5. (a) Reflection coefficient (b) Absorption characteristics for different angles of incidence

IV. Conclusion

The design of flexible ink-jet printed electromagnetic absorbers has attracted the attention of the design community. Especially the conformal nature of these designs can find immense utility in military applications. These structures are to be optimized to enhance the absorption bandwidth. The article describes the design of an optimized structure that offers a 90% absorption bandwidth of 600 MHz at for TE polarization and 85% absorption bandwidth of 200 MHz. In order to obtain polarization insensitive and angle insensitive absorption characteristics, symmetry conditions have to be imposed and the structure has to be optimized for all incidence angles and will be considered in future works.

References

1. R. Pelluri, N. Gupta and B. Appasani, "A multi band absorber using band gap structures," *IEEE International Conference on* Microwave *and Photonics,* pp. 1-2, Dhanbad, India, 2015.
2. R. Pelluri and B. Appasani, "Genetic algorithm optimized X-band absorber using metamaterials," *Progress in Electromagnetics Research*, vol. 69, pp.59-64, 2017.
3. B. S. Cook and A. Shamim, "Inkjet printing of novel wideband and high gain antennas on low-cost paper substrate," *IEEE Trans. Antennas Propag.*, vol. 60, no. 9, pp. 4148–4156, 2012.
4. B. S. Cook and A. Shamim, "Utilizing wideband AMC structures for high-gain inkjet-printed antennas on lossy paper substrate," *IEEE Antennas Wirel Propag. Lett.*, vol. 12, pp. 76–79, 2013.
5. V. Lakafosis, A. Rida, R. Vyas, L. Yang, S. Nikolaou, and M. M. Tentzeris, "Progress towards the first wireless sensor networks consisting of inkjet-printed, paper-based RFID-enabled sensor tags," *Proc. IEEE*, vol. 98, no. 9, pp. 1601–1609, 2010.
6. L. Yang, A. Rida, R. Vyas, and M. M. Tentzeris, "RFID tag and RF structures on a paper substrate using inkjet-printing technology," *IEEE Trans. Microw. Theory Tech*., vol. 55, no. 12, pp. 2894–2901, 2007.
7. G. Shaker, S. Safavi-Naeini, N. Sangary, and M. M. Tentzeris, "Inkjet printing of ultrawideband (UWB) antennas on paper-based substrates," *IEEE Antennas Wirel. Propag. Lett., vol*. 10, pp. 111–114, 2011.
8. M. Bozzi, M. M. Tentzeris, V. Lakafosis, T. Le, S. Kim, R. Vyas, A. Georgiadis, J. Cooper, B. Cook, R. Moro, A. Collado, and H. Lee, "Inkjet-printed antennas, sensors and circuits on paper substrate," *IET Microwaves, Antennas Propag*., vol. 7, no. 10, pp. 858–868, 2013.
9. R. Vyas, V. Lakafosis, A. Rida, N. Chaisilwattana, S. Travis, J. Pan, and M. M. Tentzeris, "Paper-based RFID-enabled wireless platforms for sensing applications," *IEEE Trans. Microw. Theory Tech*., vol. 57, no. 5, pp. 1370–1382, 2009.
10. A. Rida, L. Yang, R. Vyas, and M. M. Tentzeris, "Conductive inkjet-printed antennas on flexible low-cost paper-based substrates for RFID and WSN applications," *IEEE Antennas Propag. Mag*., vol. 51, no. 3, pp. 13–23, 2009.
11. U. P. Substrates, L. Yang, S. Basat, A. Rida, and M. M. Tentzeris, "Design and development of novel miniaturized UHF RFID tags on ultra-low-cost paper-based substrates," *Electron. Des*., 2006.
12. M. Yoo, H. K. Kim, S. Kim, M. Tentzeris, and S. Lim, "Silver Nanopart-based inkjet-printed metamaterial absorber on flexible paper," *IEEE Antennas Wirel. Propag. Lett*., vol. 0, no. 2, pp. 1–1, 2015.
13. B. Appasani, V. K. Verma, R. Pelluri, and N. Gupta, "Genetic algorithm optimized electromagnetic band gap structure for wide band noise suppression," *Progress in Electromagnetics Research Letters*, vol. 71, 109-115, 2017