Thin Metamaterial Absorber Made of Randomly Distributed Cut Carbon Sticks

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***Abstract* - In this paper a new type of metamaterial absorber is presented, which is realized by a non-periodic pattern of low conductive carbon sticks, which are deployed randomly on a highly flexible dielectric substrate above a perfect electric conductor (PEC). The absorber works in the frequency band around 10 GHz and provides good absorption over a wide bandwidth and is more or less independent to the incoming polarization of the wave. Due to the selected materials an outdoor application is possible.**

***Index Terms* — Absorbers, FSS, metamaterial.**

I. INTRODUCTION

Periodic structures or arrangements of equally spaced and identical elements have been of interest in many areas of electromagnetic engineering. Named as frequency selective surfaces (FSS) or metamaterials they show filter behavior for electromagnetic waves [1]. Using these types of metamaterials as absorbers, a high surface impedance has to be generated in order to provide absorption of the incoming wave. Classical metamaterial absorbers are mostly characterized by a strictly geometrically arranged pattern of electrical highly conductive materials. The length and shape of the pattern defines the center frequency of maximum absorption. In the past, metamaterial absorbers were presented which were made of cutted conductive wires, either with ideal perfect conductivity or with reduced conductivity [2]. In [3] advantages regarding polarization effects are shown. In this paper, a new approach was made in such a way, that the periodic structure of the FSS has been given up. Instead, the FSS was designed by a non periodic structure, made of randomly distributed conductive sticks. The length of the sticks defines the center frequency of maximum absorption, as well as the geometry and material parameters of the complete absorber. Main advantage of this structure is its insensitivity to signal polarization.

II. ABSORBER SIMULATION

Metamaterial behavior can be achieved by using a structure or pattern which is related to the wavelength. Therefore an investigation was performed whether conductive sticks which are randomly distributed above a PEC will show absorptive behavior. This was achieved by simulations. Quadratic sticks with length l made of low conductive material ($\sigma = 100$ S/m) were randomly distributed on a 4 mm thick dielectric sheet of low permittivity ($\varepsilon r = 1.3$) and above PEC. In the simulation, the sticks did not touch each other and were arranged in an irregular pattern. Fig. 1 shows such an example.

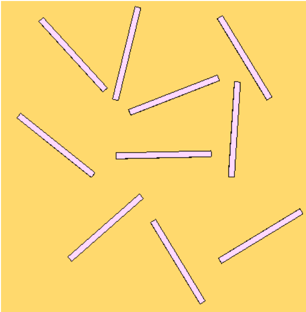

Fig. 1. Non periodic FSS

Of course for the simulations a periodic boundary structure was used. However, each stick alone, as linear array would already provide absorption. Therefore the overall dimension of the unit cell has been extended in both directions in such a way that it was big enough to achieve the non periodic structure. The cell consist of 10 sticks, with variable length between 8 and 10.5 mm. Fig. 2 shows the result of the simulations.

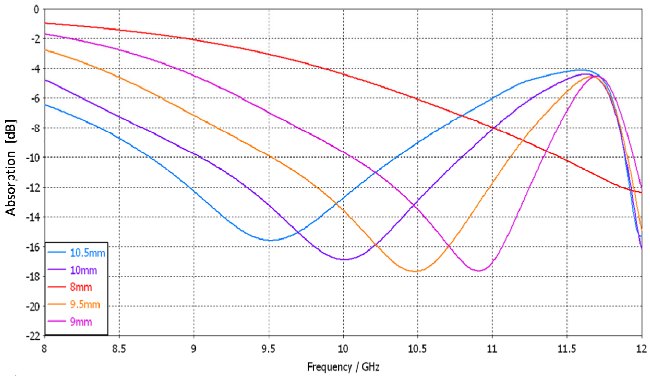

Fig. 2. Absorption behavior of the structure as a function of the stick length.

Similar to a linearly arranged periodic pattern, absorption behavior can be seen. The center frequency is in the 10 GHz frequency range and can be influenced by the length of the sticks. By reducing the length of the sticks the center frequency increases. In the simulation the height of the sticks was 0.3 mm and the width was 0.5 mm. Other material parameters, as the conductivity of the sticks, or permittivity and height of the substrate, had also significant influence on the center frequency. Fig. 3 shows the absorption as a function of the polarization angle of the incoming wave. With the exception of a slight shift in frequency more or less no difference in absorption appears. This means, that the irregular structure is also insensitive to the polarization of the incoming wave.

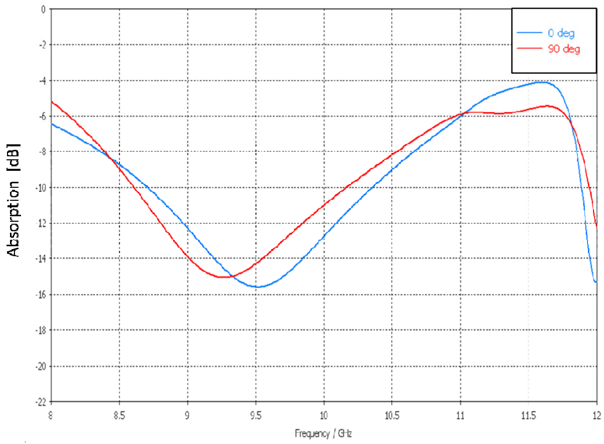

Fig. 3. Influence of polarization with 10.5 mm sticks.

III. FINAL DESIGN AND MEASUREMENT

Finally, a variety of electromagnetic simulations were performed to optimize the dimension of the sticks and the thickness of the dielectric layer for optimum absorption. In addition bandwidth and parameter sensitivity under consideration of a practical realization of the absorbers were made. As basis for practical absorber design, the above found results were used to create an absorber for a center frequency of 9.4 GHz. The laminated substrate was made of a highly flexible sheet of 3.4 mm thick chloroprene layer ($\varepsilon_r = 1.3$, $\tan\delta = 0.03$) with a top cover of 0.3 mm thick and also highly flexible polyurethane layer. The PEC ground side consists of an alumnium foil. The elongated carbon sticks are cut out of a polyurethane laminated carbon fleece. Depending on the carbon concentration of the laminate and by modifying the exact length, width and thickness of the small carbon sticks, and most important the area density of the sticks, the desired absorption could be achieved. Fig. 4 shows the final measurement result of the absorber. At center frequency a typical absorption of more than 20 dB results over a wide bandwidth of approximately 1 GHz. The most critical parameter besides the length of the sticks was an optimized equal stick density on the substrate. Too less or too many sticks per area reduced the absorption depth of the absorber. Therefore enormous care had to be taken to provide an equal stick density across a huge panel area. As the absorbers are mounted in rough outdoor environment special care had to be taken to fulfill the rugged mechanical requirements. Therefore a final flexible polyurethane top coating for protection was added. The above described absorber is designed for practical industrial application as a flat panel coating for metal constructions.

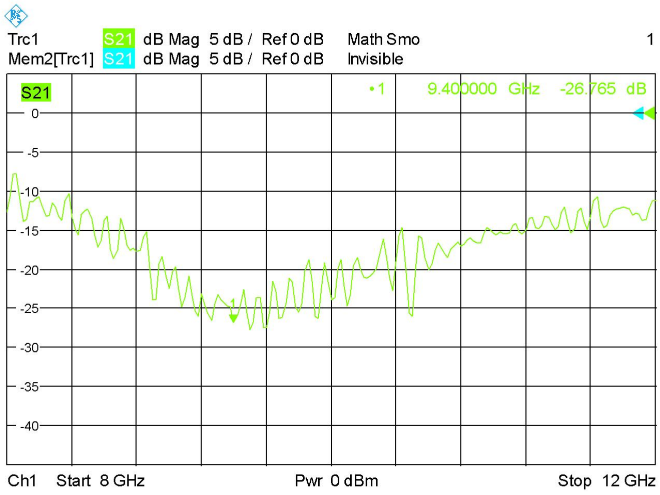

Fig. 4. Measurement result of the absorber (stick length 9.0 mm).

IV. CONCLUSIONS

A new type of metamaterial absorber has been presented, which shows, in contrast to other publications, a non periodic pattern composed by randomly distributed carbon sticks made out of low conductive material. The influence of the geometry, the size of the sticks and the used materials has been proved by simulations. The absorber was built and showed good absorption in the desired frequency band at 9.4 GHz. The measurement results are in good agreement with the simulations. Due to the randomly deployed cut carbon sticks the absorption is inured to the polarization of the incoming wave. The absorber is made of flexible but robust material that can be used for outdoor applications. The overall development process shows that this type of new metamaterial absorber is well suited for industrial applications.

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