Materials Research Bulletin 96 (2017) 250–253

Contents lists available at ScienceDirect

Materials Research Bulletin

journal homepage: www.elsevier.com/locate/matresbu

A dual-polarized metamaterial-based cloak

Sikder Sunbeam Islam[a,*], Mohammad Rashed Iqbal Faruque[a], Mohammad Tariqul Islam[b]

[a] Space Science Centre (ANGKASA), Institute of Climate Change (IPI), Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[b] Dept. of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 5 October 2016
Received in revised form 6 February 2017
Accepted 24 February 2017
Available online 27 February 2017

Keywords:
Cloak
Metamaterial
Dual-polarization

ABSTRACT

A new metamaterial-based dual-polarized rectangular single layer electromagnetic invisibility cloak is being introduced in this study. Initially, a bare-H-shaped metamaterial unit cell was designed on FR-4 dielectric material. Finite integration technique-based electromagnetic simulator was adopted to design the metamaterial and explore the material's effective medium properties. Measured result for the metamaterial was provided as well. Then the proposed metamaterial was employed in the construction of a new dual-polarized rectangular cloak. The newly developed cloak shields a metal object from view electromagnetically by controlling the electromagnetic fields. The cloak was found performing the cloaking operation from the frequency of 5.04 GHz–9.47 GHz that covers certain region of C- and X-band of microwave spectrum.

1. Introduction

After the invention of metamaterial, it is being utilized in many interesting fields of electromagnetic arena including cloak design. Metamaterial is an artificially constructed composite material that shows some exotic electromagnetic properties those are unavailable in natural materials. Cloaking is one of the most interesting applications of metamaterial. An electromagnetic cloak is a device that can hide something by passing electromagnetic fields around an object. Cloaking devices are needed to hide structures like satellites and military aircrafts from hostile radar systems. There have been various approaches developed for cloaking in the literature [1–5]. The first development of cloak to solve the invisibility intricacy, the approaches of transformation optics (TO) was introduced where the cloak medium was built by metamaterials [1]. This type of cloaks is good for hiding even large object but suffers from design complexity and large structures. However, in this context, scattering reduction technique for cloaking is better due to proper performance, simplicity and ease of construction. Metamaterial-based cloaking using scattering reduction method was also realized earlier [6]. This popular method of cloaking creates opposite dipole moment between object core and metamaterial shell for hiding an object. An object can be hidden electromagnetically if it does not scatter wave in any direction. Metamaterial with negative effective permittivity is suitable for suppressing the scattering of an object and eventually utilized for scattering reduction method to cloak [7]. Usually, a good cloak reduces the normalized scattering width (NSW) or radar cross section (RCS) per unit length of an object below one [6]. Previously few studies were performed on metamaterial-based cloak. However, most of the cloaks were cylindrical in shape. Very few metamaterial-based non-cylindrical cloaks were proposed in the literature but their cloaking performances were not demonstrated for dual polarized operations and wideband applications. Recently in [8], a two-component near zero refractive index (NZRI) metamaterial-based rectangular single layer cloak was proposed but cloak operation was not proven for dual polarization. Moreover, their cloak not operates for multi-band or wideband region. Another, metasurface based cloak was claimed in [9] for dual incident polarization but it was applicable for S-band only. Moreover, it was a cylindrical-shaped cloak. There are few wideband cloak were proposed in the literature like, in [10] a metamaterial based wideband cloak was proposed operating in the C-band covers 900 MHz region only. Dielectric material based broadband cloak was proposed in [11] operating in the S-band only and three types of dielectric materials were utilized.

In this study, a design of a new metamaterial for dual polarized electromagnetic cloaking operation is presented. Initially, a bare-H-shaped metamaterial unit cell was designed on FR-4 substrate material. The metamaterial was adopted for designing a

* Corresponding author.
E-mail addresses: sikder_islam@yahoo.co.uk (S.S. Islam), rashedgen@yahoo.com (M.R. Iqbal Faruque), titareq@gmail.com (M.T. Islam).

http://dx.doi.org/10.1016/j.materresbull.2017.02.039
0025-5408/

rectangular cloak. The cloak operates in the certain regions of C- and X-band for dual polarization.

2. Materials and method

The structure of the proposed metamaterial unit cell consists of a bare-H-shape (i.e., empty H-shape) that was embedded in a FR-4 dielectric material. The unit cell is presented in Fig. 1. The thickness of the dielectric material was kept 1.6 mm and with dielectric property ε = 4.3 + 0.02i. The width and the length of the dielectric material was, L = 12 mm. A 0.035 mm thick copper layer was utilized for making the structure on the substrate material. The design parameters of the structure are *l* = *10*, *g* = *0.46*, *s* = *0.2*, *d* = *2.50*, *c* = *2.77*, *b* = *4.77*, *a* = *6*, all in mm scale seen in Fig. 1. Two gaps in the top and bottom surface was kept 0.46 mm. The whole design structure contains few LC-circuits. When the structure will be illuminated by a plain electromagnetic wave, currents are induced in each length of the structure that constitute charge in the wire end and eventually forms capacitance in each gap. The capacitive effect leads to create negative effective permittivity.

The metamaterial unit cell sample is excited by the plain wave with propagation vector along the *z*-axis, parallel electric field along the *y*-axis and magnetic field parallel to the *x*-axis. Finite integration technique based simulator was adopted for the full wave simulation to estimate the S-parameters and perfect electromagnetic boundary condition was applied. The S-parameters were used to calculate the effective parameters of the sample adopting the Nicolson-Ross-Weir method [12].

Beside the numerical investigation, experimental test also performed for the metamaterial. For the experimental validation, two waveguides and a VNA (vector network analyzer) N5227A were utilized. A fabricated prototype of unit cell was prepared for measurement purpose. The fabricated unit cell prototype is seen in Fig. 2. The two waveguides were connected to the VNA. The prototype was placed between two waveguides facing each other and S-parameters were measured.

3. Result and discussion

In Fig. 3a, the simulated transmittance for the basic material unit cell is presented. Two transmittances are seen from that figure at the frequency of 4.29 GHz and 9.93 GHz.

It is evident that the minimum wavelength is more than three times bigger than the size of the bare-H-shape atom that supports the effective medium property of the proposed metamaterial. Beside the simulation result, the experimental outcome was provided in Fig. 3a as well for the validation. The measured result shows good agreement with the simulation results. The Fig. 3b displays the permittivity characteristics of the unit cell. The real peak of permittivity curve shows negative region over two frequency bands those are 4 GHz–4.43 GHz and 5.42 GHz–9.26 GHz. However, it is apparent that the second band covers more than 3.80 GHz frequency bandwidth and it has started just after the plasma frequency. This long negative region of permittivity has significant prospect for designing a cloak.

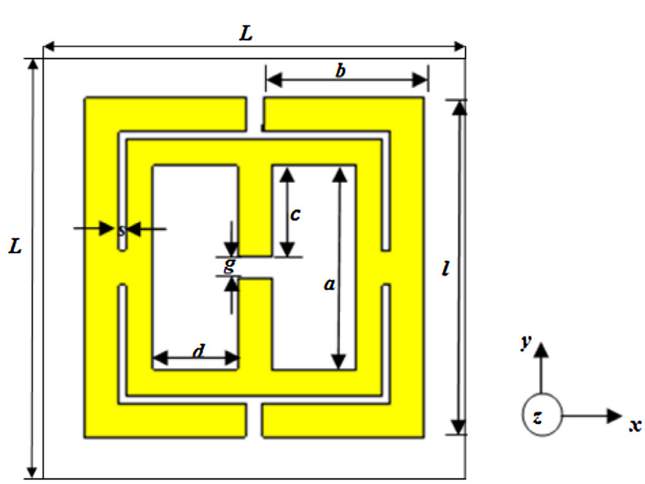

Fig. 1. Unit cell of Bare-H-Shape.

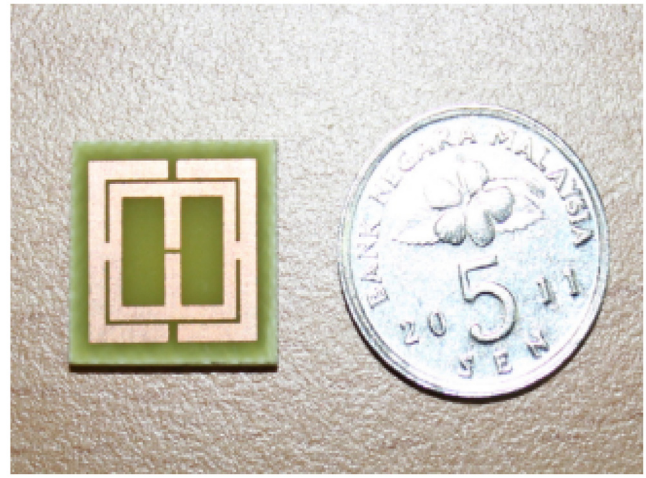

Fig. 2. Fabricated metamaterial unit cell.

4. Metamaterial-based cloak design

In the further step, a rectangular cloak was designed using the proposed metamaterial. For designing a rectangular cloak, four unequal metamaterial walls were prepared. For the length of the cloak two walls containing 2 × 2 metamaterial unit cell, were used at two sides of the cloak. Similarly, along the width of the cloak, two walls having 1 × 1 metamaterial unit cell were utilized at the two opposite sides of the cloak. An aluminium cylinder having same height of the cloak with inner and outer radius 4 mm and 5 mm was inserted in the cloak.

The Fig. 4a shows the cloak structure with object inside. According to Fig. 4a, transverse electric wave was propagated through the *x*-axis and y-axis consecutively of the cloak for the respective horizontal (along the length of the cloak) and vertical polarization (along the width of the cloak).

4.1. For the x-axis propagation

The Fig. 4b shows the normalized scattering width (NSW) of the cloaked object normalized to the bare object for the *x*-axis propagation through the cloak. It is visible that, the cloak shows normalized scattering width below one from the frequency of 5.04 GHz–9.47 GHz that covers more than 4 GHz bandwidth in the certain region of C- and X-band of microwave spectra. This region can be regarded as the cloaking zone, where the object can be hidden. Moreover, the metamaterial unit cell is also showing negative permittivity at that region.

Fig. 5 depicts the E-field circulation of the uncloaked object. It is seen that, for *x*-axis wave propagation, from the surface of the bare object the field is being scattered at the forward direction and therefore zero-field region is seen at the right side of the bare metallic object.

Similarly, Fig. 6 shows field map of the object inside the cloak shell. For the wave propagation, along the *x*-axis of the cloak with