W-band Millimeter Wave Artificial Magnetic Conductor realization by grounded Frequency Selective Surface


Vrije Universiteit Brussel, Department of Electronics and Informatics
Laboratory for Micro- and Photonelectronics
Pleinlaan 2, 1050 Brussels, Belgium
E-mail: sislam@etro.vub.ac.be

A W-band millimeter wave Artificial Magnetic Conductor (AMC) is realized by using a grounded Frequency Selective Surface (FSS) array of different dimensions of resonant slots. Unlike normal conductors, this new surface does not support propagating surface waves, and it reflects electromagnetic waves with no phase reversal. Geometrically it consists of slots on a metallic layer on top of metal backed Roger 4003C\textsuperscript{TM} dielectric substrate. Commercial CST Microwave studio software is used for simulation FSS cells and the S-parameters are characterized with a free space VNA. The simulation and experimental results demonstrate that the structure behaves like an AMC in W-band.

Introduction

The tangential magnetic field on the surface of a magnetic conductor is zero. The reflection of TE wave at the surface of magnetic conductor is in-phase with the incidence wave, rather than opposite-phase as in the case of electric conductor surface. Furthermore, propagating surface waves are not supported by such a surface. The natural magnetic conductor does not exist in reality, but can be approximately performed artificially by two dimensional array of metallic patches etched on the surface of dielectric sheet or by slotted FSS structures [1]. Such a hypothetical magnetic conductor may be very useful in a wide range of applications [2]. The performances of these kinds of Artificial Magnetic conductors (MAC) structures are sensitive to the frequency. They can be realized within a limited frequency range as the of structures work as resonators. In fact, the phase of reflection coefficient of TE wave, \( \phi = 0^\circ \) at resonant frequency and the frequency range satisfying \( |\phi| < 90^\circ \) is defined as the available frequency band of AMC realization in engineering application [3]. In some applications AMC structure is needed in wide frequency range. There are several ways to increase the frequency range of such structures. In this paper, we have presented an artificial Magnetic conductor where the array is composed of FSS cells of different slot dimensions to increase its frequency band. The slot dimensions are the main parameter that controls the frequency band of the AMC structure. In this work, we will first extract a basic FSS cell from AMC structure and will characterize it as AMC in a limited frequency range and secondly we will explain the characteristics of FSS array which is composed with such FSS cells with different slot dimensions. This FSS structure represents AMC surface with anisotropic impedance characteristics controlled by the resonance properties of periodic slot dimensions in the presence of a grounded dielectric substrate on the back side of the structure.

AMC Structure with grounded FSS

Proceedings Symposium IEEE/LEOS Benelux Chapter, 2007, Brussels
The two-dimensional FSS array of resonant elements can be viewed as a kind of electric filter, and many of its properties can be explained using a simple LC circuit model [5]. The capacitance is due to the width of the slot, while the inductance originates from the length of the slot. The impedance of a parallel resonant LC circuit is qualitatively similar to the tangent function. It is inductive at low frequencies, and thus supports TM surface waves. It is capacitive at high frequencies, and supports TE surface waves. In a narrow band around the LC resonance, the impedance is very high. In this frequency range, currents on the surface radiate very efficiently, and the structure suppresses the propagation of both types of surface waves. Having high surface impedance, it also reflects external electromagnetic waves without the phase reversal that occurs on a flat conductor. In fact, the AMC condition is characterized by the frequencies where the magnitude/phase $|\tau|/\angle \tau$ of the reflection coefficient is $1/0^\circ$ [4]. When surface impedance ($Z_s$) is low, the reflection phase is $\pm \pi$. When $Z_s$ is very high, the reflection phase is zero. The phase crosses through $\pm \pi/2$ when $Z_s$ is equal in magnitude to the impedance of free space.

The realized FSS array consists of periodically perforated slots backed by grounded Roger 4003C substrate. The structure consists of rectangular slots in 1.5 $\mu$m Al top of 1489 $\mu$m grounded Roger 4003C substrate with dielectric constant $\varepsilon_r=3.38$ and loss tangent 0.0027. A 10 $\mu$m BCB-Layer (Benzo-Cyclo-Butene) layer was deposited between the Aluminum and Roger 4003C to level the roughness of the Roger 4003C surface. To design a FSS the thickness of the substrate, the size of the unit cell and the length and the width of the rectangular slot have to be determined properly. The thickness $t_{rog}$ of the Roger 4003C substrate has to fit the Fabry-Perot resonance condition [6]. During the simulation of the structure, it turned out so that the FSS geometry can be adapted to $t_{rog}=1489 \mu$m wafer thickness, without deterioration of the device characteristics. The unit cell dimensions shown in Fig.1 (a) were optimized to $A=B=1400 \mu$m to get the first order resonance. The slot length can be determined from the approximate resonant condition $a_{slot} = \frac{\lambda}{2} - \frac{c}{2f\sqrt{\varepsilon_r}}$, where $\varepsilon_r=\frac{\varepsilon_f+1}{2}$.

The simulations of the structure were carried out using commercial CST Microwave studio software. To get W-band AMC behavior FSS array has been considered by mixing with different slot dimensions to incorporate the phase response. As the

---

**Figure1. Artificial Magnetic Conductors using grounded Frequency Selective Surfaces**

(a) Unit Cell of FSS (b) FSS array with variable slot dimensions
resonance frequency as well as the phase of FSS can be controlled by slot dimensions, the array was designed with five different slot dimensions and the arrangement of cells is shown in Fig.1 (b). Starting from the initial values the slots dimensions were finally determined from iterative CST simulation results. The array in figure1(b) is designed with FSS cells at resonances frequencies 78GHz, 87GHz, 94GHz, 101GHz and 103GHz which corresponds to the slot dimensions of 1300×400 µm, 1080×400 µm, 917×400 µm, 743.5×550 µm and 680×680 µm respectively.

**Experimental Results**

The reflection amplitude and phase of the FSS were measured in W- band frequency range by using a free space modulated vector network analyzer (MVNA).

![Amplitude and Phase Comparison](image)

Figure 2. Measurement and simulation comparison of a uniform FSS array with slot dimensions 1076 ×400 µm. (a) Amplitude and (b) Phase

![Amplitude and Phase Comparison](image)

Figure 3. Measurement and simulation comparison of composite FSS array in W-band (a) Amplitude and (b) Phase

Fig.2 shows the comparison of measurement and simulation of a uniform slot FSS array. At resonant frequency the simulation and measurement amplitude of $S_{11}$ are -0.753dB and -1.76dB respectively. So the loss at resonance is 1.007db. A 1.5 GHz down frequency shifting is obtained due to over etching of slots. In simulation result phase the structure experiences perfect magnetic conductor behavior at 86.95GHz with a high-impedance boundary condition of 11.25 GHz compare to the 9.5 GHz in measurement results as shown in Fig.1 (b). Fig.3 shows the comparison of measurement and expected (estimated from simulation results) of the array of mixed slot dimensions. As shown in
figure 3(a) except the minimum reflected power -3.12dB in low frequency range, the losses are less than -3dB in W-band. Fig.3 (b) shows the W-band phase behavior of the FSS of Fig.1 (b). The maximum phase variation is ±π/6 compared to perfect magnetic conductor in the whole W-band. There is some mismatch between the measurement and estimated amplitude and phase which is due to the frequency shifting effect and also for higher measurement losses. Except in very small frequency range in W-band the measurement results agree with the simulations. But the over all response of the FSS bases AMC surface is in very acceptable range.

Conclusion
W-band AMC surface is realized by using grounded FSS with different dimensions of resonant slots. The uniform cell FSS array was studied by comparison of the measurement and simulation results to show AMC behavior in limited frequency range. To increase the frequency band an artificial magnetic conductor, was designed with mixing up of different slot dimensions of FSS cells. Due to the whole W-band response of AMC the proposed structure does not suffer from frequency shifting and bandwidth limitation. Although this surface has high impedance, it is less lossy surface and the impedance is almost entirely reactive, with only a very small resistive part due to dielectric and conduction losses. Though the material loss is small, it is multiplied by the quality factor (Q) of the structure; hence a considerable higher loss is measured than the expectation.

Acknowledgment
This work was partially funded by the Vrije Universiteit Brussel (VUB-OZR), the Flemish Fund for Scientific Research (FWO- G.0041.04) and the Flemish Institute for the encouragement of innovation in science and technology (IWT-SBO 231.011114).

References