Design and Measurement of a Spiral-Cell PMC for Metamaterial Applications

P. J. Ferrer, J. M. Gonzalez-Arbesu, and J. Romeu

Electromagnetics & Photonics Engineering Group, Universitat Politecnica de Catalunya, c/Jordi Girona, 1-3, Modul D3, Campus Nord UPC, 08034 Barcelona (Spain) email: pj.ferrer@tsc.upc.edu

1 Introduction

In recent years, there has been a rising interest in metamaterials design. Artificial negative magnetic permeability mediums are generally composed by SRRs resonators, introduced by Pendry [1]. Other examples of subwavelength metamaterial structures are the BC-SRR and planar spiral resonators (SRs) [2], the capacitively-loaded loops (CLLs) [3], and the spiral resonators [4], which reduce the electrical size of the unit cell.

In this paper, spiral resonators are designed, fabricated and tested for metamaterial applications.

2 Design and simulation of the Spiral Resonators

The spiral resonators based artificial magnetic conductor (AMC) slab was designed and simulated with ANSOFT’s HFSS ver. 9.1. The spiral resonator unit cell is shown in Fig. 1. The spiral dimensions were side = 7 mm, strip width = 0.85 mm, and gap width = 0.6 mm, forming a 2-loop Greek key spiral. The spiral metal width was assumed to be infinitely thin and was treated in HFSS like a perfect electric conductor (PEC) boundary condition over each element surface. These elements were etched on fiberglass FR4 epoxy, a dielectric with \( \varepsilon_r = 4.4 \), \( \mu_r = 1.0 \), loss tangent = 0.02, and width = 0.26 mm. The unit cell dimensions were 4.5×8×8 mm\(^3\) in a \( xyz \) axis, and an incident plane wave is propagating toward the unit cell in the +z direction, with its magnetic field oriented along the –x axis and its electric field oriented along the +y axis. The region outside the metamaterial slab was filled with vacuum, \( \varepsilon_r = 1.0 \), \( \mu_r = 1.0 \).

Infinite boundary conditions (IBC) were applied in HFSS, thus only one element is needed for carrying out the simulations. Therefore, the boundary walls along the y axis were considered like PECs and the ones along the x axis like PMCs.

3 Fabrication and Measurements

The AMC slab was fabricated and measured at our department facilities. The spirals were etched by standard photoetching procedures on FR4 substrate. Finally the different lines of spirals from the dielectric board were placed on a Styrofoam board in order to form the 1-layer metamaterial slab. In fact, two metamaterial slabs were fabricated. The smaller one, composed by 22 lines of 6
spirals each one, for measuring from a waveguide; and the bigger one, composed by 43 lines with 18 spirals each one, for measuring the radiation diagrams. Moreover, when simulating with HFSS, some variations in the metamaterial slab could be considered relating to the spirals “wrapping orientation” in the infinite AMC surface due to the different images created by the PEC/PMC IBC, but obtaining the same results in the simulations. Hence, two designs of the spirals were considered for fabrication, one with the aligned spirals, and the other with symmetric spiral, as shown in Fig. 2 (left).

The fabricated metamaterial slab was firstly measured using an HP8510C network analyzer, and a WR341 waveguide calibration kit was used, working between 2.0 and 3.4 GHz for 801 points. The results are shown in Fig. 2. A dual behavior is observed. When measuring the S11, the incident plane wave propagates along \(+z\) axis, and a PMC response is found (the reflection phase crosses 0º around 2.95 GHz and the magnitude is around 2 dB). For S22, the propagating wave is along \(-z\) axis, and a PEC response is found (the reflection phase around -180º). Note that there is a slight frequency deviation between both designs (aligned and symmetric) due to the simplicity of the prototypes. The losses appeared in the magnitude results are mainly due to the fiberglass (FR4) substrate losses. These results agree with the simulations done before.

In order to show the PMC behavior the radiation pattern of a folded dipole in front and parallel to the artificial surface was carried out for different distances Fig. 3. The radiation diagrams were measured in an anechoic chamber and the results are shown in Fig. 4. The antenna patterns have been measured using a spherical near-field measuring system; the antenna under test is mounted on a roll over azimuth system and a ridge horn is used as a probe. The measurement frequency was set at 3 GHz, which corresponds to a wavelength of 10 cm. The results show that the H-plane pattern for a distance of \(\lambda/4\) to a PEC is very similar to the pattern obtained when the dipole is close to the AMC. On the other hand, a cancellation effect of 6 dB is observed when the dipole is placed at a distance of \(\lambda/4\) from the AMC.

4 Conclusion

Simulations and measurements have been carried out of a 1-layer metamaterial slab made of spiral resonators that shows an AMC behavior, with an equivalent electrical width of \(\lambda/12\) for the thickness (z dimension) of the slab. This behavior has been experimentally verified through radiation pattern measurements. The results show that similar results are obtained by placing a PEC at a \(\lambda/4\) distance and by placing the antenna close to the AMC. This latter solution is lower profile.

5 Acknowledgements

This work has been partially funded by the Spanish Ministry of Education and Science through the project TIC2003-09317-C03-03 and through the Ramon y
Cajal Programme, and by the European Commission through the METAMORPHOSE Network of Excellence.

References


Figures

Fig. 1: Spiral unit cell geometry

Fig. 2: Waveguide measurements of the S11 and S22 parameters of the metamaterial slab, Magnitude (left) and Phase (right)
Fig. 3: Different views of the designs measured in the anechoic chamber: dipole over ground plane GP (left), and dipole over metamaterial slab (right)

Fig 4: Measured H plane pattern of a folded-dipole antenna over a ground plane (GP) and a perfect magnetic conductor (PMC) at different distances at 3 GHz
专注于微波、射频、天线设计人才的培养

网址: http://www.edatop.com

射频和天线设计培训课程推荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于2006年整合合并微波EDA网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和ADS、HFSS等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

射频工程师养成培训课程套装

该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共30门视频培训课程和3本图书教材；旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求...

课程网址：http://www.edatop.com/peixun/rfe/110.html

ADS学习培训课程套装

该套装是迄今国内最全面、最权威的ADS培训教程，共包含10门ADS学习培训课程。课程是由具有多年ADS使用经验的微波射频与通信系统设计领域资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了ADS在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用ADS，迅速提升个人技术能力，把ADS真正应用到实际研发工作中去，成为ADS设计专家...


HFSS学习培训课程套装

该套课程套装包含了本站全部HFSS培训课程，是迄今国内最全面、最专业的HFSS培训教程套装，可以帮助您从零开始，全面深入学习HFSS的各项功能和在多个方面的工程应用。购买套装，更可超值赠送3个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的HFSS学习更加轻松顺畅...

课程网址：http://www.edatop.com/peixun/hfss/11.html
CST 学习培训课程套装

该培训套装由易迪拓培训联合微波EDA网共同推出，是最全面、系统、专业的CST微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您零开始，全面系统地学习CST微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送3个月免费学习答疑…


HFSS 天线设计培训课程套装

套装包含6门视频课程和1本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了HFSS天线设计的全过程。是国内最全面、最专业的HFSS天线设计课程，可以帮助您快速学习掌握如何使用HFSS设计天线，让天线设计不再难…

课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含4门视频培训课程，培训将13.56MHz线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了13.56MHz线圈天线的工作原理、设计方法、设计考量以及使用HFSS和CST仿真分析线圈天线的具体操作，同时还介绍了13.56MHz线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握13.56MHz线圈天线及其匹配电路的原理、设计和调试…


我们的课程优势：

※ 成立于2004年，10多年丰富的行业经验，
※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求
※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

联系我们：

※ 易迪拓培训官网：http://www.edatop.com
※ 微波EDA网：http://www.mweda.com
※ 官方淘宝店：http://shop36920890.taobao.com