Compact Planar Antenna Structures using Metamaterials

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Abstract
This paper is based on Compact Planar Antenna designs. Metamaterial antennas are a class of antennas which use metamaterial structures to increase the performance of the patch antenna. They exhibit properties such as negative permittivity and negative refraction. To implement this, repeated pattern is created in the antenna surface which thereby shows the property of metamaterials. Reactive Impedance Surfaces are elements which mimics the property of metamaterials in such a way that these substances replace metamaterials while designing the antenna. In this paper, a novel design that incorporates mushroom structures, split ring resonators and 'eyebrow structures' were designed to get better output characteristics. Concurrently, various metamaterial antenna structures were studied, simulated and their performance characteristics were analyzed using HFSS software.

Keywords
Ansys HFSS, Metamaterial, Split Ring Resonator (SRR), Complementary Split Ring Resonator(CSRR), Eyebrow, Mushroom Structure, Reactive Impedance Surface (RIS)

I. Introduction

In recent years, metamaterials have received great attention due to their unusual properties and behaviours. However, most metamaterial researches are still limited to the theory and numerical simulations, and only a few experiments have been performed. This project was an overview on the currently used metamaterial antennas and how its performance can be improved by modifying its parameters. Initially, we studied the HFSS (high frequency structural simulator) software. It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging. Firstly we designed a basic patch antenna structure and simulated its results using HFSS software. Thereafter, we simulated two papers namely "Compact Circularly-Polarized Patch Antenna Loaded With Metamaterial Structures" by Yuandan Dong, Hiroshi Toyao, and Tatsuo Itoh IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 11, NOVEMBER 2011" and "Design and Characterization of Miniaturized Patch Antennas Loaded With Complementary Split-Ring Resonators" by Yuandan Dong, Student Member, IEEE, Hiroshi Toyao, and Tatsuo Itoh, Life Fellow, IEEE, IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 60, NO. 2, FEBRUARY 2012 using ansoft HFSS and observed the results. Later we made some modification in the above design to bring improvements in antenna characteristics.

II. Models and Configeration

A. Configuration of Rectangular Patch Antenna

At the initial level of our project, we studied the basic aspect of HFSS software. Thereafter we designed a simple rectangular patch antenna operating at 2.4Ghz. The basic design of patch antenna consists of substrate, ground, patch and a coaxial feed. The substrate dimensions are designed to be 100mm x 90mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm. The probe is made of coaxial cable of which the outer conductor and the inner conductor is made of Perfect Electric Conductor (PEC) of radius 1.6mm and 0.7mm respectively. The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is extended up to the patch antenna.

The HFSS model is shown in fig. 1, the s_{11} (reflection coefficient) plot is shown in Graph 1 and these values are given in table 1.

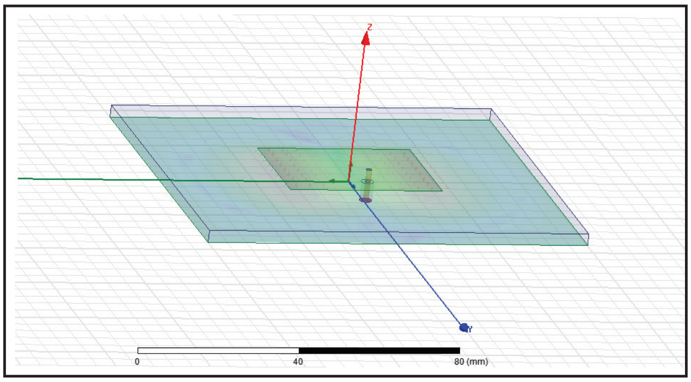
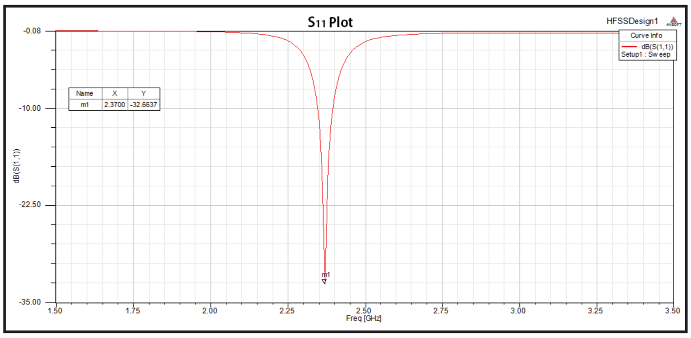


Fig. 1: Configuration of Rectangular Patch Antenna

Table 1:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.
Basic patch antenna	-32.66	2.37



Graph 1: Variation of Reflection Coefficient Against Frequency for a Rectangular Patch Antenna

B. Configuration of Compact Circularly Polarised Patch Antenna Loaded With Metamaterial Structures

As the next step, we implemented an IEEE transaction paper to implement a compact circularly polarized antenna using Reactive Impedence Surface (RIS) and mushroom structure operating at 2.4Ghz. RIS is a two dimensional periodic metallic patches printed on a grounded substrate that exhibits metamaterial property (Metasurface). Mushroom structures are a combination of shorting pins with square metallic patches placed on top of the pins which is shown in fig. 2.

The substrate dimensions are designed to be 36.2mm x 36.2mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm.

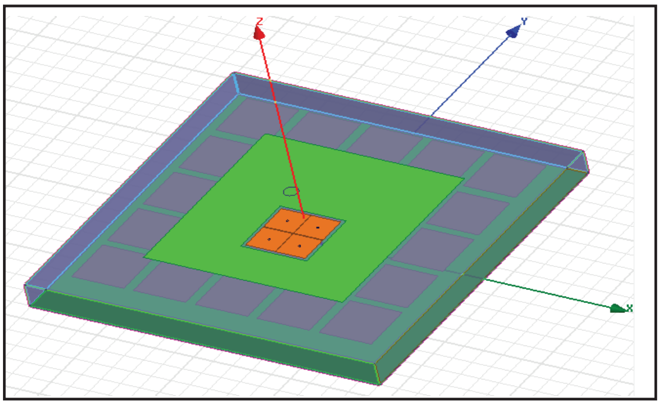
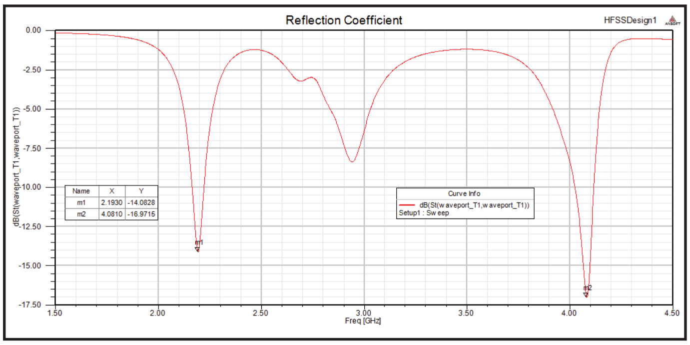


Fig. 2: Configuration of Compact Circularly Polarized Patch Antenna loaded with metamaterial structures(Mushroom structure) [courtesy to "Compact Circularly-Polarized Patch Antenna Loaded with Metamaterial Structures" Yuandan Dong, Hiroshi Toyao, and Tatsuo Itoh IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 11, NOVEMBER 2011]

The HFSS model is shown in fig. 2, the s_{11} (reflection coefficient) plot is shown in Graph 2 and these values are given in Table 2.

The graph 2 shows dual band operation operating at 2.19 Ghz and 4.08 Ghz. Hence the same antenna can be operated at two different frequencies. Here, the antenna size is brought down by a factor of 85.4% compared with basic patch design.



Graph 2: Variation of Reflection coefficient against frequency for a Compact Circularly Polarized Patch Antenna loaded with metamaterial structures(Mushroom Structures)

Table 2:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.
Patch antenna with Mushroom structures	-14.08 -16.97	2.19 4.08

C. Configuration of Patch Antennas Loaded With Complementary Split-Ring Resonators

As the next step, we implemented an IEEE transaction paper to implement a Patch Antennas Loaded With Complementary Split-Ring Resonators operating at 2.4Ghz. RIS is a two dimensional periodic metallic patches printed on a grounded substrate that exhibits metamaterial property (Metasurface).

A Split-Ring Resonator (SRR) is an artificially produced structure common to metamaterials. Their purpose is to produce the desired magnetic susceptibility (magnetic response) in various types of metamaterials. These media create the necessary strong magnetic coupling to an applied electromagnetic field, not otherwise available in conventional materials. An effect such as negative permeability is produced with a periodic array of split ring resonators. A single cell SRR has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped as needed. A magnetic flux penetrating the metal rings will induce rotating currents in the rings, which produce their own flux to enhance or oppose the incident field (depending on the SRRs resonant properties). Due to splits in the rings the structure can support resonant wavelengths much larger than the diameter of the rings. This would not happen in closed rings. The small gaps between the rings produces large capacitance values which lower the resonating frequency. The dimensions of the structure are small compared to the resonant wavelength. Complementary split ring resonator are obtained by replacing the copper parts with substrate material and vise versa. They are seen to the better performance when compared to split ring resonators.

The substrate dimensions are designed to be 33.9mm x 33.9mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm.

The HFSS model is shown in fig. 3, the s_{11} (reflection coefficient) plot is shown in Graph 3 and these values are given in Table 3.

The graph 3 shows dual band operation operating at 2.27 Ghz and 2.65 Ghz. Hence the same antenna can be operated at two different frequencies. Here, the antenna size is brought down by a factor of 87.23% compared with basic patch design.

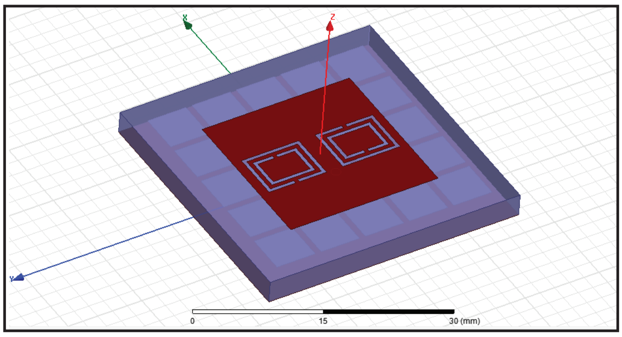
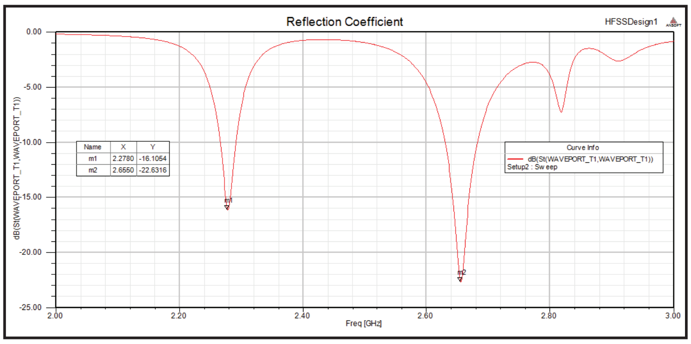


Fig. 3: Patch antenna loaded with CSRR [courtesy to "Design and Characterization of Miniaturized Patch Antennas Loaded With Complementary Split-Ring Resonators" Yuandan Dong, Hiroshi Toyao, and Tatsuo Ito,IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 60, NO. 2, FEBRUARY 2012]



Graph.3 Variation of Reflection coefficient against frequency for a Configuration of Patch Antennas Loaded With Complementary Split-Ring Resonators

Table 3:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.
CSRR patch antenna	-16.11 -22.63	2.27 2.65

III. Modified Structures

By modifying the above structures we implemented three new designs.

A. Increasing the Number of CSRR Structures

In this modification, we increase the number of CSRR structures. The substrate dimensions are designed to be 33.9mm x 33.9mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm.

The HFSS model is shown in fig. 4, the s_{11} (reflection coefficient) plot is shown in Graph 4 and these values are given in Table 4.

The Graph 4 shows dual band operation operating at 2.27 Ghz and 2.67 Ghz. Hence the same antenna can be operated at two different frequencies. Here the s11 parameter is further decreased from -16.11dB to -16.18dB and-22.63dB to -26.43dB.

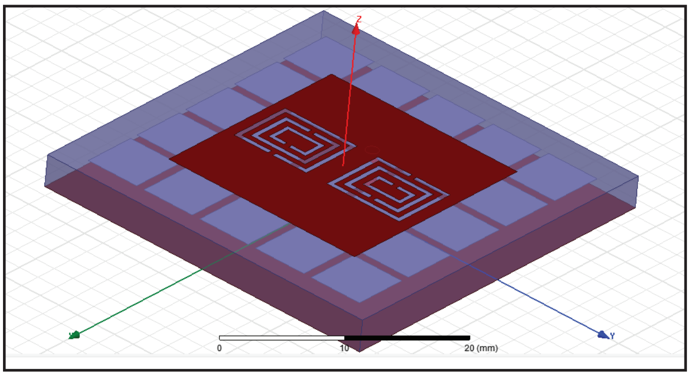
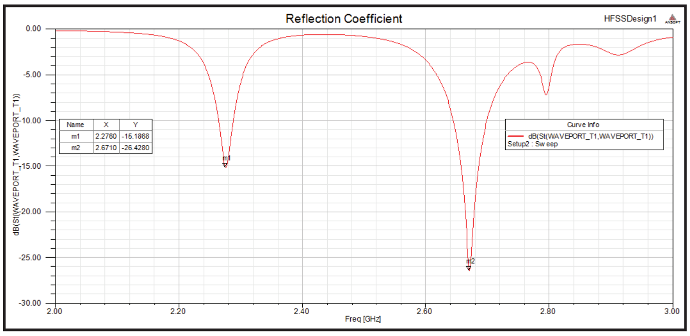


Fig. 4: Increasing the Number of CSRR Structures



Graph 4: Variation of Reflection Coefficient Against Frequency After Increasing the Number of SRR Structures

Table 4:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.
Modified CSRR patch antenna	-16.18 -26.43	2.27 2.67

B. Combining Both Mushroom and CSRR in a Single Design

In this modification, we combine both mushroom and CSRR in a single design. The substrate dimensions are designed to be 33.9mm x 33.9mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm.

The HFSS model is shown in fig. 5, the s_{11} (reflection coefficient) plot is shown in Graph 5 and these values are given in Table 5.

The Graph 5 shows triple band operation operating at 2.25 Ghz , 2.67 Ghz and 2.78 Ghz. Hence the same antenna can be operated at three different frequencies. Here the s_{11} parameters are observed to be -21.03dB, -24.55dB and -28.66dB.

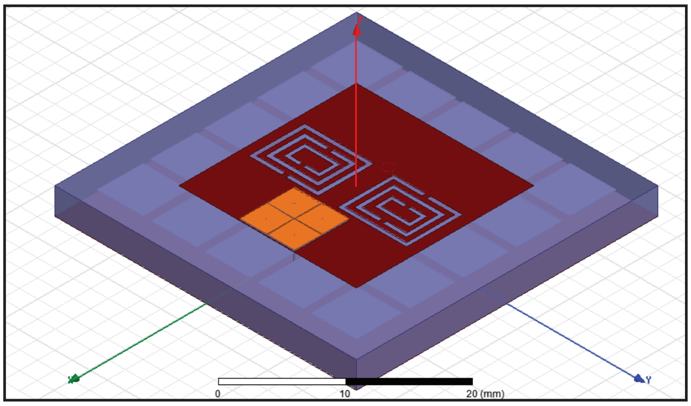
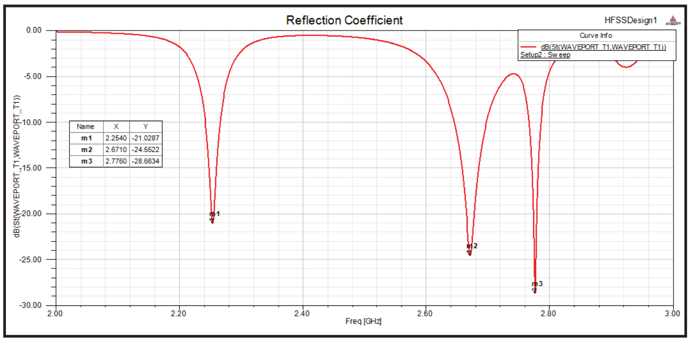


Fig. 5: Combining Both Mushroom and CSRR in a Single Design



Graph 5: Variation of Reflection Coefficient Against Frequency After Combining Both Mushroom and CSRR in a Single Design

Table 5:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.
CSRR patch antenna with mushroom structures	-21.03 -24.55 -28.66	2.25 2.67 2.78

C. The Eyebrow Structures

In this modification, we introduced a new structure which can be called as eyebrow structures. Here, changes are made to the CSRR structure to obtain the eyebrow structure. The substrate dimensions are designed to be 33.9mm x 33.9mm. The substrate material used is MEGTRON6 having a permittivity of 4.02 and dielectric loss tangent as 0.009. The height of substrate used is 3mm.

The HFSS model is shown in fig. 6, the s_{11} (reflection coefficient) plot is shown in Graph 6 and these values are given in Table 6. The Graph 6 shows dual band operation operating at 2.24 Ghz and 2.62 Ghz. Hence the same antenna can be operated at two different frequencies. Here the s_{11} parameters are observed to be -22.23dB and -26.16dB.

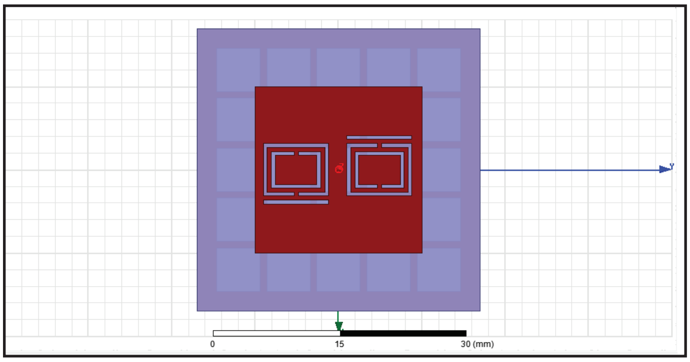
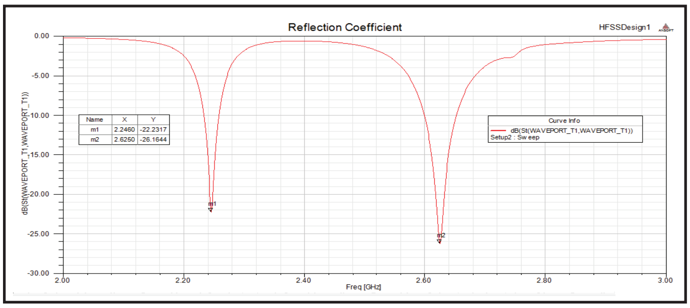


Fig. 6: Configuration of Patch Antenna Loaded With Single Eyebrow Structures



Graph 6: Variation of Reflection Coefficient Against Frequency for a Novel Design Including Eyebrow Structures

Table 6:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.	Dimension mm x mm
Eyebrow	-22.23 -26.16	2.24 2.62	33.9 x 33.9

IV. Consolidation of all the Above Results

Table 7 shows consolidation of all the results which have been simulated.

Table 7:

Design	S_{11}(Reflection Coeff.) dB	Frequency Ghz.	Dimension (mm x mm)
Basic patch antenna for 2.4Ghz freq.	-32.6	2.37	100 x 90
Mushroom structures in RIS	-14.08 -16.97	2.19 4.08	36.2 x 36.2
Circularly polarised patch antenna with RIS and CSRR	-16.11 -22.63	2.27 2.65	33.9 x 33.9
Combining both mushroom and CSRR in a single design	-21.03 -24.55 -28.66	2.25 2.67 2.78	33.9 x 33.9
Single Eyebrow	-22.23 -26.16	2.24 2.62	33.9 x 33.9

Comparing different structures, combining both mushroom and CSRR in a single design shows good results and also gives a triple band response. Single Eyebrow structure also shows good results in its dual Reflection Coefficient response. For determining the best antenna for use in a specific application, we need to arrive at trade-offs between the desired characteristics, namely gain, reflection coefficient, frequency of operation, bandwidth, size etc.

V. Acknowledgment

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