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Design and Analysis of Frequency Reconfigurable Antenna Loaded Complimentary Split Ring Resonator for Wireless Applications

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Abstract
This paper presents a multi-band reconfigurable antenna, circular patch antenna loaded with combination of rectangular and infinity shape complementary split ring resonator (CSRR). Four slots used for connecting the rectangular with infinity CSRR, where the four PIN diodes loaded in order to achieve reconfigurability. The circular patch has printed in Roger RT/5880 substrate having a dielectric constant of 2.2 within a size 37.35x34.35x1.57. Extraction of permittivity negative of the CSRR is discussed in detail. The proposed antenna can be used in modern and mobile communication devices.

Keyword: CSRR, Meta-material, infinity CSRR, rectangular CSRR, reconfigurable antenna, Multi-band antenna, negative permittivity, L-band, S-band, C-band

I- Introduction

In order to improve the performance of an antenna, the use of new materials becomes indispensable. Meta-materials are the most widely used artificial materials since their invention by the physicist Pendery [1]. Split ring resonators and complementary split ring resonators are the basic structures of meta-materials whose negative effective permeability and negative effective permittivity they have introduced respectively [2][3]. Meta-materials have an exceptional design whose electrical permittivity and magnetic permeability can be modified by adjusting the unit and its geometrical parameters. The negativity of these two parameters leads to a unique property of these materials such as negative refractive index, electromagnetic cloak, and energy collection [4]. Meta-materials are also called left-handed or double negative materials by combining metallic wires with split ring resonators to create both negative effective permittivity and negative effective permeability [5]. In [6][7], a rectangular complementary split-ring resonator (RCSRR) array was etched into the ground plane to achieve dual-band and reconfigurable dual-band operation respectively. A frequency reconfigurable multiband antenna is presented in [8], The combination between the slots and the complementary split ring resonator due to the multiband. and reconfiguration is achieved by switching the PIN diode between the ON and OFF state in the ground plane. Frequency reconfigurability can be achieved by inspiring negative permeability meta-materials of rectangular shape to achieve tri-band operation [9], multiband reconfiguration [10] and infinite shape to achieve broadband reconfigurability [11].

In this paper, new complementary split ring resonator geometry has been loaded into the ground plane to create a reconfigurable multi-band operation, the proposed antenna covers two main bands; C-band and S-band. The simulation is done by two solvers, CST and HFSS.

II- Antenna configuration

A basic antenna with a circular patch was designed using cavity method [12]. It printed on a 37.35x34.35x1.57 mm3 RT/ROGERS 5880 substrate with a relative permittvity $\varepsilon_r = 2.2$ and dissipation factor 0.0009.

The patch antenna is 6.87 mm in size, the ground plane is 37.35x34.35 mm2, and the feed line is 4.87x17.13 mm2. For better matching, a quarter wave transformer is placed between circular patch and feed line.The proposed antenna is built to resonate at 5.9GHz.

The proposed antenna configuration has a circular micro-strip patch with which the different parameters have been calculated. Fig.1. depicted the geometry of the upper and lower surface of the antenna.

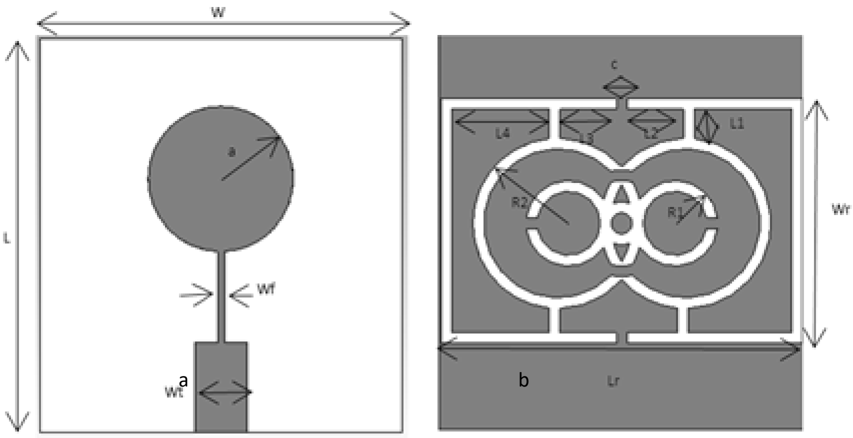

Fig.1. proposed antenna geometry (a) top view, (b) bottom view

Table.1. Design Parameters of the proposed Antenna

Parameters	L	W	Lr	Wr	a	R1	R2	Wt	Wf	L1	L2	L3	L4	c
Dimension (mm)	37.35	34.35	23	34	6.87	4	8	4.87	0.6	2.75	5.3	5.3	9.2	1

III- Negative permittivity extraction

The complementary split-ring resonator is a new structure for the resolution of left-handed meta-materials and negative permittivity. It presents the counterpart of split-ring resonator. The complementary split-ring resonator consists of bricks based on radiating elements in order to acquire a medium with negative effective permittivity. The excitation of this structure is based on the incident electrical field that is parallel to the normal of the plane where the CSRR is located.

The most widely used method to extract the negative permittivity is the Nicolson, Ross-Weir (NRW) method which is based on the measurement of S-parameters. They can relate the input parameters to the output parameters in such a system [14].

$$V_{max} = S_{11} + S_{21} \tag{15}$$

$$V_{min} = S_{21} - S_{11} \tag{16}$$

$$\varepsilon_r = \frac{\lambda(1-V_{max})}{j\pi h(1+V_{max})} \quad (17)$$

$$\mu_r = \frac{\lambda(1-V_{\min})}{j\pi h(1+V_{min})} \quad (18)$$

Fig.2. shows the proposed structure of the complementary split ring resonator. It printed on the RT/ROGERS 5880 substrate. The simulation is done by the computer Simulation Technology (CST) simulator based on the finite integration technique (FIT).

The proposed split ring resonator is composed of infinite split ring resonator [11] and rectangular split ring resonator linked by stubs. The role of the proposed complementary split ring resonator is to generate a new frequency in order to achieve a multiband. This is confirmed by creating bandwidth that appears at 7.992 GHz and 8.474 GHz (Fig.3.). The elementary cell is placed in a waveguide limited by the magnetic field and the electric field along the x-axis and the y-axis respectively. The ports are placed along the Z-axis. The negative value of the effective permittivity of the structure appears in 3 frequencies; 7.902 GHz with a value of -70.22, 8.106 with a value of -46.78, and 8.176 GH with a value of -69.51 (Fig.4). Negative permeability is obtained when the antenna has exposed a new frequency in the return loss characteristics.

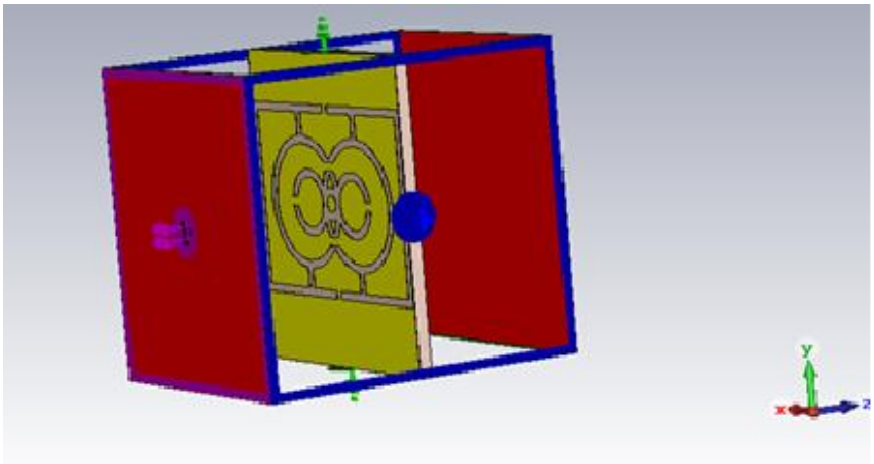

Fig.2. CSRR unit cell in waveguide setup

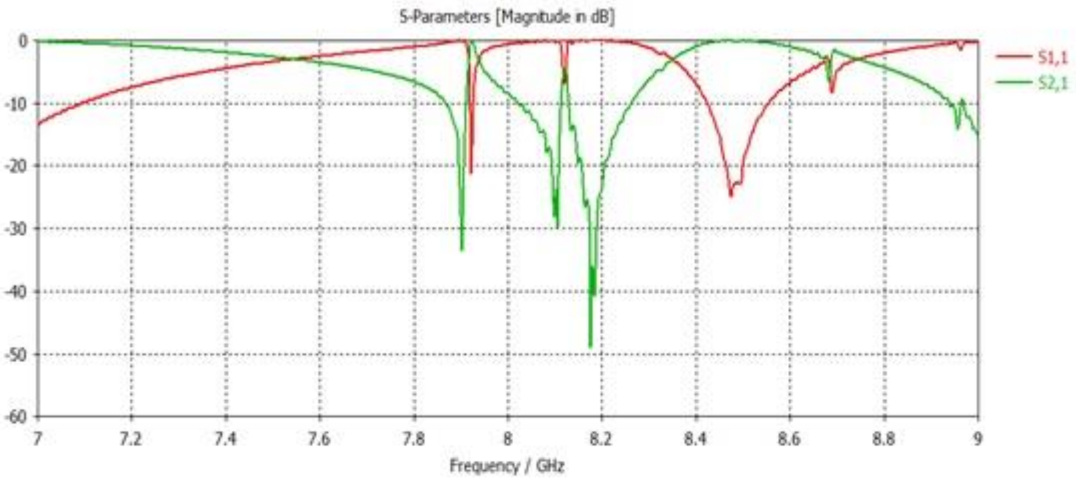

Fig.3. Reflection and transmission coefficient plots vs frequency

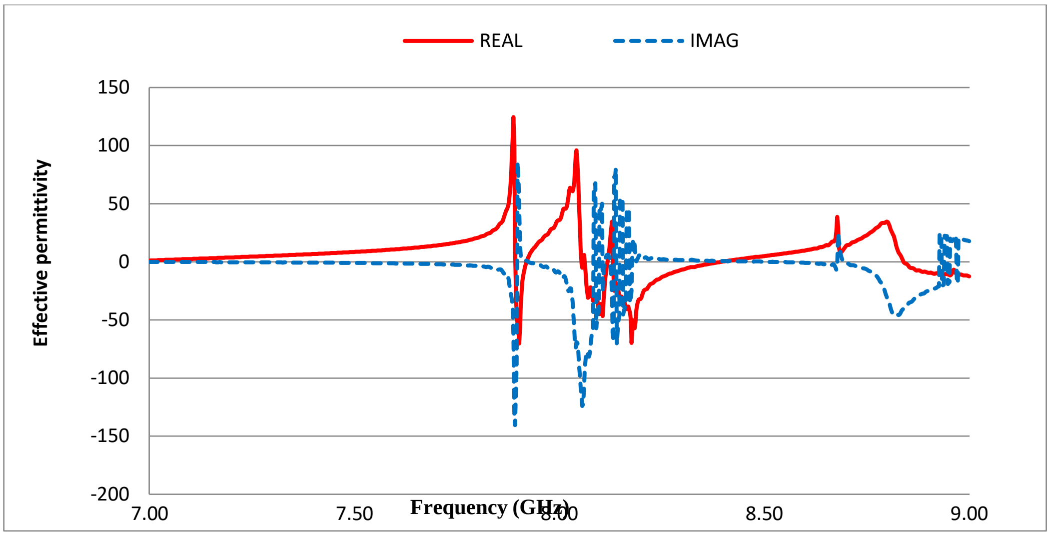

Fig.4. Extracted real and imaginary permittivity plot vs frequency

IV- Results and discussion

IV-1- Coefficient of reflection

The proposed antenna has been designed to meet the needs of wireless applications. The achievement of several standards is a great challenge. In this work, this challenge has been overcome. The proposed structure covers three frequency bands; L-band, S-band, and C-band.

The switching of four diodes integrated into the ground plane allows the antenna to resonate in these different standards. The switching of the diodes between the ON and OFF states leads to four modes after several tests performed. Fig.5. shows the results of the reflection coefficient. This is the parameter that describes the matching of the transmission line with the radiating element. based on the results presented in the table, it appears that the transmission line is well suited to the patch.

One of the disadvantages of micro-strip antennas is to have a narrow band. Frequency reconfiguration technology increases bandwidth. The combination of these two concepts has allowed us to achieve three frequency bands: the first is 229MHz, the second is 452 MHz and the last is 636 MHz.

the value of the standing wave ratio (VSWR) for the resulting frequency bands is optimum. they are between 1 and 2, which means that the majority of the power received from the generator has been transferred to the antenna (Table.2.)

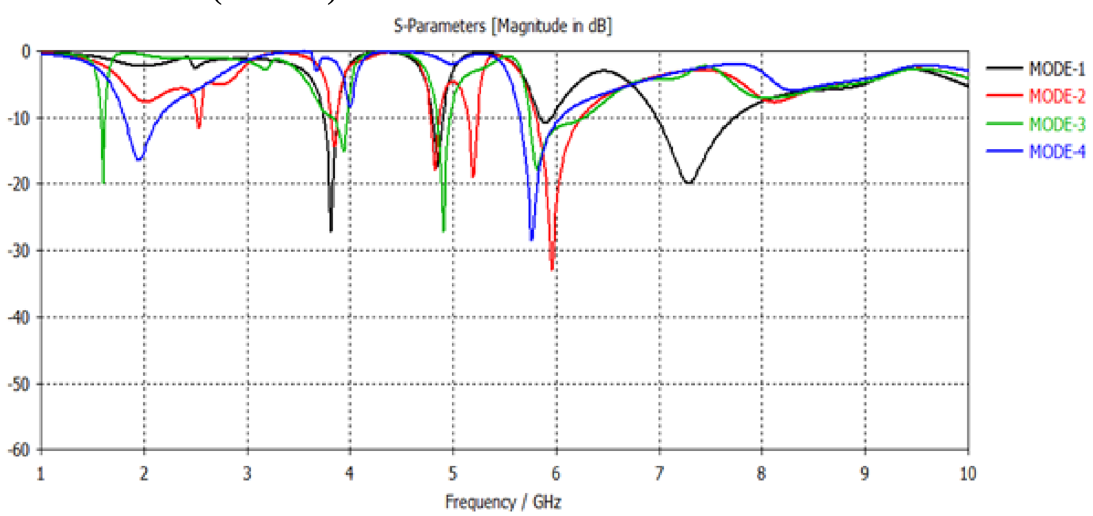

Fig.5. Simulated S11 value of the proposed antenna

Table.2. Diodes modes, S11 and VSWR values

Modes	D1	D2	D3	D4	F (GHz)	S11 (dB)	VSWR
1	ON	ON	ON	ON	3.817	-27.27	1.09
					4.852	-17.44	1.31
					5.896	-10.89	1.79
					7.28	-19.93	1.22
2	ON	OFF	ON	OFF	3.844	-14.35	1.47
					4.825	-17.8	1.29
					5.2	-18.58	1.26
					5.959	-32.97	1.04
3	OFF	ON	ON	OFF	3.934	-15.02	1.43
					4.9	-27.16	1.09
					5.815	-17.78	1.29
4	OFF	OFF	OFF	OFF	1.945	-16.35	1.35
					5.761	-28.4	1.04

IV-2- Gain and Efficiency

The simulated gain and efficiency are summarized in Table3. The proposed antenna covers the UMTS band in mode 4 for frequency 1.945 GHz for gain 1.89 dB and efficiency of value 83.05%. The same structure resonates at RLAN band for frequency 5.2 GHz, the value of 3.36 dB of gain and 76.73% of efficiency value. Another indispensable band has been appearing in mode 4 is Industrial, Scientific and Medical (ISM) band at frequency 5.761 GHz with 4.99 dB for gain and 92.38% for efficiency values.
The band that answers to the intelligent transport communication (Intelligent Transportation System (ITS)) is shown in mode 1 has for gain of value 5.32 dB and efficiency 95.08%.
In general, the proposed antenna is covering the L,S and C bands. It has a minimal gain for the 1.24 dB value. The maximum gain is 5.93 dB for the 7.28 GHz frequency in mode 1. The minimum efficiency is 32.24% and the maximum efficiency is for the 95.08 value for the ITS band.
The proposed complementary split ring resonator gives the good performance of the proposed antenna, which means that the hypothesis of meta-materials improve the performance of such antenna is true.

Table.3. Gain, Directivity and Efficiency values

Modes	Gain (dB)	Directivity (dBi)	Efficiency (%)
1	1.24 – 4.2 - 5.32 - 5.93	2.48 – 4.79- 5.54 – 6.29	75.05 – 87.46 – 95.08 – 92.05
2	2.32 – 4.63 – 3.36 – 4.21	3.35 – 5.19 – 4.51 – 4.64	78.89 – 88.1 – 76.73 – 90.68
3	1.87 – 4.78 – 4.45	3.15 – 5.45 – 4.93	74.49 – 85.67 – 89.59
4	1.89 – 4.99	2.7 – 5.34	83.05 – 92.38

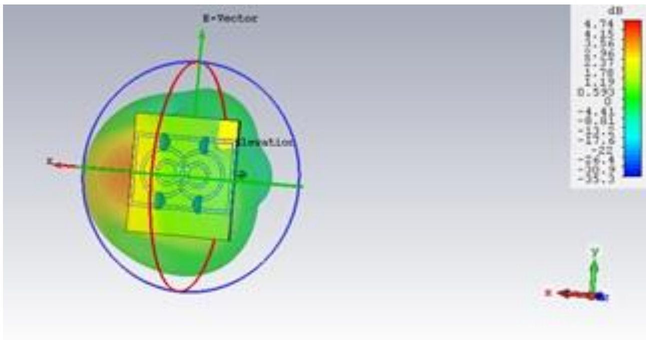

Fig.6. location of antenna and location of PIN diodes

IV-3- Radiation Pattern

The radiation pattern is a graphical presentation of the radiation properties of an antenna in space. It describes how the antenna transmits or receives energy to or from space. The antenna's radiates characteristics were analyzed using a 2D radiation pattern, for each resonant frequency of the four operational modes. The analysis of this radiation is done by the projection of energy in two main planes; the azimuth plane and the elevation plane. In this work the proposed antenna has been simulated for the four modes (Fig.7.) for most of the frequency bands, the radiation pattern in the azimuth plane is in the form of a circle and in the elevation plane it appears as a shape of eight.

The proposed reconfigurable antenna are compared to other references in Table.4.

Table.4. comparison of the proposed antenna with state-of-art reconfigurable antenna

Ref.	Size (mm3)	N° of PIN diodes	N° of bands	Gain (dB)	Efficiency (%)
[10]	23.37x29x1.524	6	10	0.634 -3.75	55 – 81
[15]	17x28x1.6	3	8	1.5 – 3.85	82 - 89
[16]	25.2x23.7x1.6	1	5	<3.49	Not given
[17]	27x25x1.6	1	3	1.97 – 2.98	Not given
[18]	44x39x1.6	1	6	2.12 – 4.10	41.2 – 84.7
This work	**37x34x1.57**	**4**	**13**	**1.24 – 5.93**	**74.49 – 95.08**

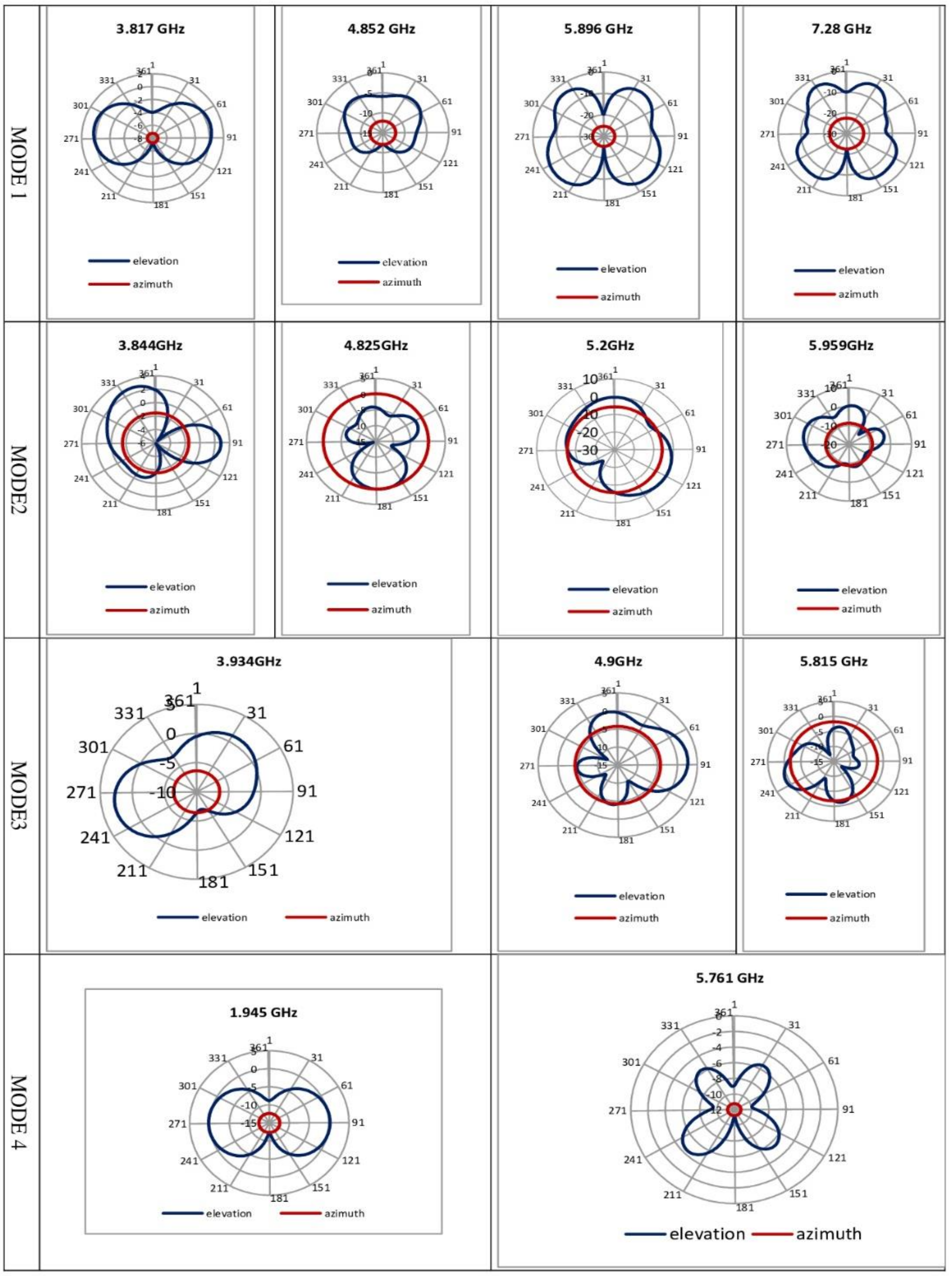

Fig.7. Simulated radiation pattern at resonant frequencies of the antenna

V- Comparison with HFSS:

The poposed structure was designed in the High Frequency Structure Simulation (HFSS) simulator to validate the results obtained by the CST simulator (Fig.8). since we have worked on reconfigurability at the frequency level, we have targeted the comparison of results at that level. Fig.9. presents the comparison of S11 reflexion parameters simulated by the CST simulator and by the HFSS which are based on fninie integration technique and finite element methods respectively. It appears that the results are similar. This makes the proposed antenna effective for use in different wireless communication applications.

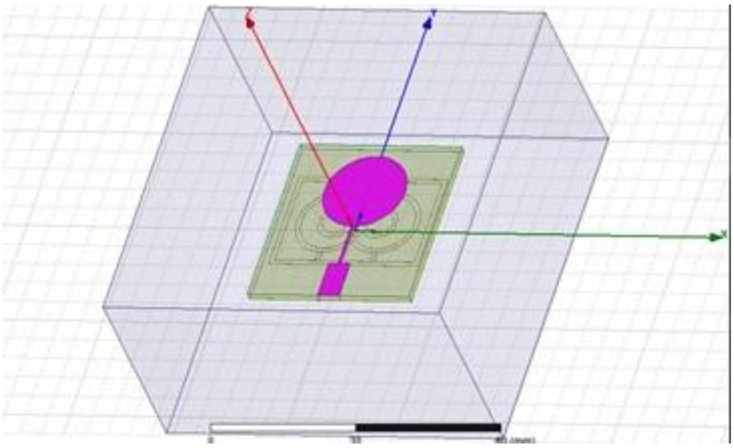

Fig.8. design of proposed antenna in HFSS

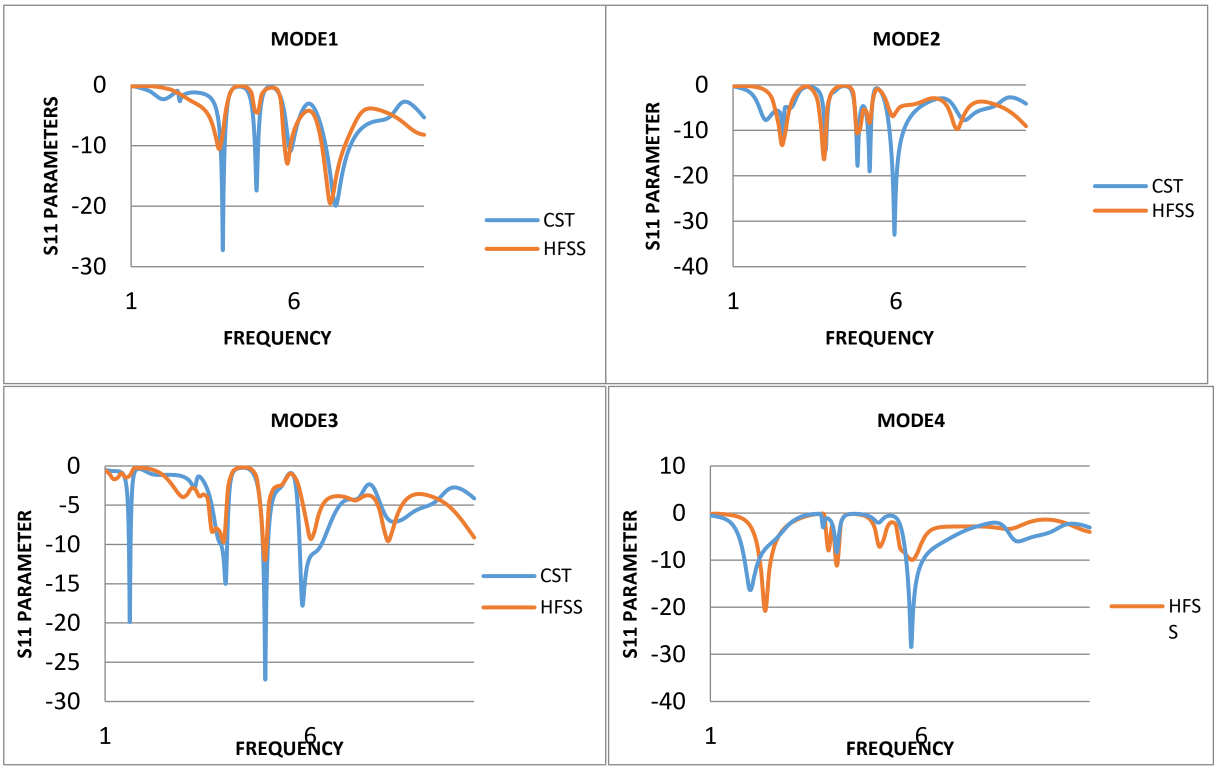

Fig.9. comparison between S-parameters in HFSSv15 and CSTv16

VI- Conclusion

In this paper, a new multiband reconfigurable antenna using complementary Split resonator with 13 frequencies was presented. The proposed antenna was designed to cover L,S, and C bands for wireless communication. The reconfigurable technique is achieved by switching between the ON State and OFF state of PIN diodes that loaded within ground plane. The proposed antenna resonates around 4GHz, 5GHz, and 6GHz. It gives an acceptable gain (1.24-5.93 dB), acceptable efficiency (74.49 – 95%) in the desired frequencies bands. The radiation pattern of antenna is omnidirectional. The proposed antenna has an affordable size which enables them to be easily integrated into portable devices for wireless communication.

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