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Mutual Coupling Reduction between Microstip Antennas Usingcomplementary Split Spiral Resonators (Cssrs)

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Abstract: *New structure of a single negative metamaterial (SNG) is achieved to reduce the mutual coupling between two nearby microstrip antennaswith only 0.5λ_0 ($\lambda_0$is the free-space wavelength) between them. Both antennasradiate in the same frequency band. The new structure consists of three complementary split spiral unit cells which are etched on the ground of the proposed antenna. This design improves the rejection response in terms of bandwidth and suppression. By using the new structure, it was possible to achieve a 23-dB reduction in the mutual coupling between the two microstrip patch antennas at resonance frequency of 6.58 GHz. Since the proposed split spiral structures are broadband, they can be used to minimize coupling and co-channel interference in multiband antennas.The reduction of the mutual coupling is achieved by EM solver simulating and measuring the reflection and transmission coefficients of the designed antenna arrays.*

I. Introduction

Nowadays due to the multiple antennas used in the same structure to operate at different and same frequency bands, the inserted antennas are suffering from strong coupling and high interference. Thus, urgent need for reducing such coupling effects to improve the performance of communication systems in such equipment is pressing hard. A several methods and techniques were used to reduce the mutual coupling and interference between microstrip patch antennas such as electromagnetic band-gap (EBG) structures using the mushroom-like topology [1], and EBG structures with insertion of vias have been applied to reduce the mutual coupling of the elements in microstrip phased arrays [2]. In addition, using slottedcomplementary split-ring resonators (SCSRR) [3], and Low-profile folded split-ring resonators (FSRR) [4] are other approaches to reduce coupling between microstrip antenna elements in arrays that is to use metamaterial (MTM) elements between the two patches.

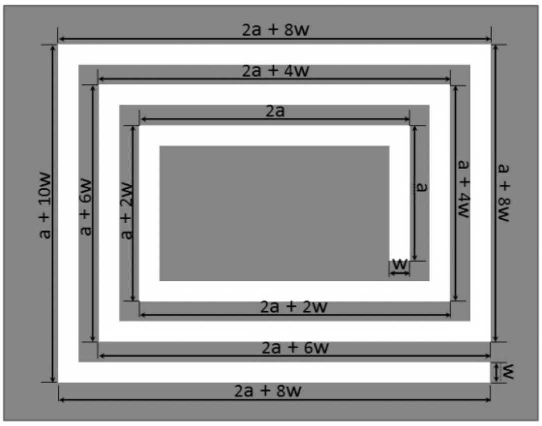


Figure 1.Complementary Split Spiral Resonator (CSSR) unit cell.

The MTM structure operates within certain frequency bands with its effective permittivity and permeability have opposite signs acting as a single negative material (SNG) or have same negative signs acting as a double negative material (DNG).

In this paper, mutual coupling reduction between two microstrip patch antennas is achieved by using complementary split spiral resonators (CSSRs) as shown in Fig. 1.This structureis capable of reducing surface, guided and near waves within certain frequency band. The technique of MTM structure that used to reduce the mutual coupling is the single negative material (SNG). This structure is easily etched, minimizes size of antenna compared to EBG, improves the isolation between the antenna arrays, and widens the stop band. The proposed split spiral shape resonator keeps the antenna having low-profile, lightweight, and the far-field properties are practically unchanged. Also the proposed spiral shape resonator achieves a 23-dB reduction in the mutual coupling and interference effects.

II. Cssr Caracterization

Before using the CSSR unit cells between the patch antennas to reduce the mutual coupling, these CSSR need to be characterized first by calculating its effective permittivity and permeability.One way to characterize metamaterials is to examine their reflection and transmission responses as functions of the frequency [6]. To derive these reflection and transmission characteristics (S_{11} and S_{21}), the metamaterial unit cell is illuminated with four plane wavesas shown in Fig.2 which is used to extract the effective permittivity. Then, the reflection and transmission coefficients are computed by the HFSS solver with the Periodic Boundary Conditions (PBC) applied to the four sides of the unit cell, and the radiation type of absorbing boundaries of the unit cell.Constitutive parameters Mu_{r_eff}, Eps_{r_eff}can be characterized by using PBC which is less computationally expensive than simulation of a finite metamaterial structure. The high frequency structure simulator (Ansoft HFSS 15) has been used to analyze the unit cell. The dimensions of the unit cell are shown in Fig.1.

The single negative material (SNG) cannot exist naturally over microwave frequencies so engineered artificial materials are developed and used to realize such materials, according to use some shapes for reflecting the waves incident to it into another directions, this known as metamaterial. The complex refraction index and characteristic impedance of a medium are important parameters for characterizing wave propagation inside such medium. The components of effective permittivity for CSSR unit cell are calculated and illustrated [3] as shown in Fig. 3. The complementary resonators emulatematerials with complex electric permittivity with negative real part above theresonance frequency of the unit cell and positive real part below resonance.Contrariwise artificial magnetic materials, which provide complex magnetic permeability withnegative real part above the magnetic inclusion's resonance frequency and positive realpart below resonance [3]. Because of the opposite signs of the two parameters ε and μ, these structures can block the surface waves inside the substrate of the antenna and guide them in other directions.

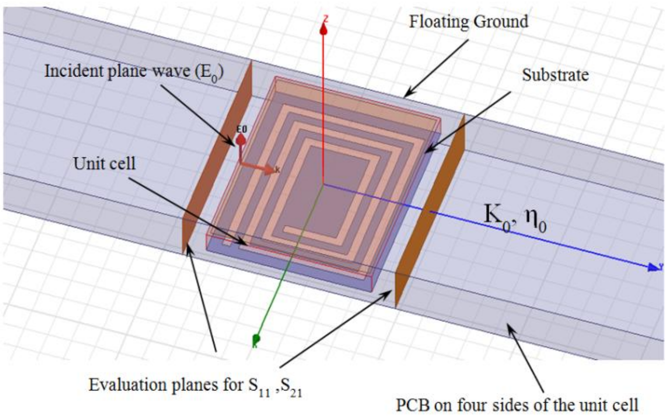


Figure 2.Simulation geometry for numerical retrieval of the effective parameters of metamaterials using Complementary Split Spiral Resonator (CSSR) unit cell.

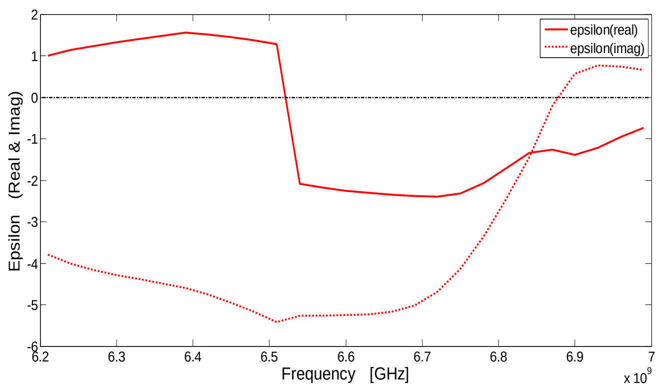
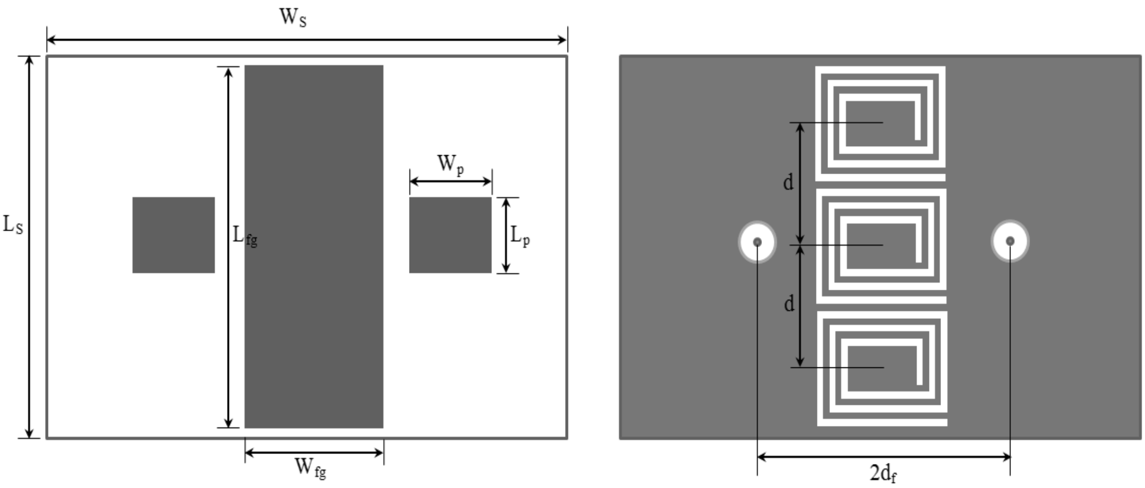


Figure 3.The real and imaginary components of effective permittivity.

III. Antenna Design

The geometry of the antenna array, where two identical microstrip patch antenna having resonance frequency of 6.58 GHzis shown in Fig.4.The two patches are placed $0.5\lambda_0$ apart between their nearest edges with λ_0 is the free space wavelength. The antenna designed on a printed circuit board (PCB) with overall size of 60 x 40 mm^2.The substrate material type is FR-4 and has a relative permittivity of $\varepsilon_r = 4.4$ and loss tangent of tan $\delta = 0.02$. The thickness of the FR-4 substrate is 1.5 mm. The two patches have dimensions (L_p= 8 mm, W_p= 9.5 mm) with overall ground dimensions of L_s = 40 mm, W_s = 60 mm “the substrate dimensions”. The dimensions of the unit cell are shown in Fig.1 with a = 5 mm and w = 0.7 mm. The complementary split spiral structure is etched on the ground plane of the antenna and a floating ground (the ground of the metamaterial) is inserted between the two patches on the top view of the substrate. The floating ground has dimensions of L_{fg} = 38 mm, W_{fg} = 16 mm. Each patch is excited on its symmetrical axis by a 50 Ω microstrip probe feed with an inset feed point of (d_f = 13.7 mm) from the center of the substrate. The three proposed CSSR isolator structure are arrangement vertically and etched on the ground plane of the antenna. The middle one is centered between the two patches and the two other split spirals are vertically separated by d = 12.5 mm center to center as shown in Fig.4 (b).



(a) (b)

Figure 4. The proposed microstrip antenna (a) The top view of antenna with two patches and the floating ground between them, (b) Bottom view with CSSRs etched on the ground plane.

IV. Results And Discussion

The antenna array is designed to work at a frequency of 6.58 GHz with probe fed patch antennas. At first, we used only one complementary split spiral resonator etched on the ground plane of the antenna at the center between the two patches and checked the results. In the second design, we used three complementary split spiral resonators arranged vertically as shown in Fig.4. In Fig. 5, the comparison between $S_{11}$and S_{21} in the two caseswith one CSSR and with three vertically CSSRs is shown. When we used one complementary split spiral resonator between the two patches, the coupling factor S_{21} has gone down by a maximum value of 13-dB. The proposed antenna system with three spirals achieves a 23-dB reduction of the transmission coefficient S_{21}as shown in Fig.5. The comparison between the simulated results of the proposed antenna with and without three complementary split spiral resonator (CSSR) is shown in Fig.6. Without CSSR, the coupling factor S_{21} parameter of the proposed antenna was approximately 21-dB and with CSSR the coupling factor S_{21}becomes 44-dB that means it has gone down by approximately 23-dB.The S_{11} also was improved with adding CSSR structures as shown.

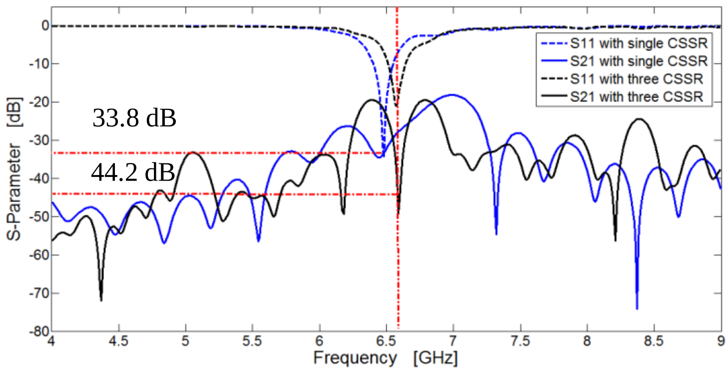


Figure 5. Comparison between a single and three complementary split spiral resonators.

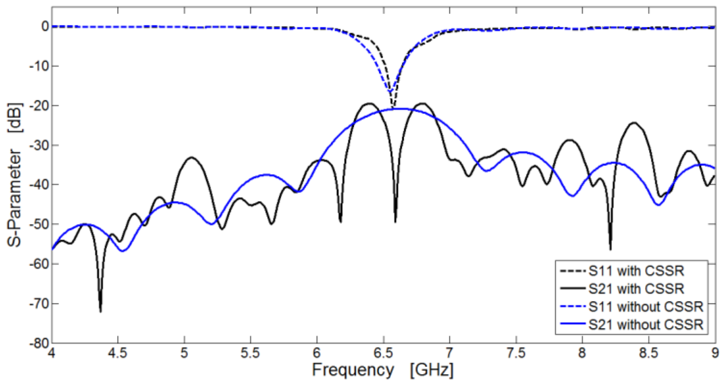


Figure 6.Comparison between the proposed antenna with three complementary split spiral resonator and without CSSRs.

A parametric study of all design dimensions is also carried out. Fig.7 shows the simulated S-parameters (S_{11} and S_{21}) as a function of the distance between the CSSRs (d) from center to center. The distance between the CSSRs (d) varied from 12.25 to 12.75 mm with step 0.25 mm. Results show that with increasing the distance d, the coupling factor S_{21} has gone up by limitand the curve moves upward with respect to the return loss (S_{11}) so we choose the distanced = 12.5 mm. Note that,when we study the variation of any dimension, we fixed all other dimensions. We study the effect of the dimension of the floating ground (L_{fg} and W_{fg}) and other dimensions.

Fig. 8 shows that the metamaterials can enhance the gain of the proposed antenna also the presence of CSSRs in the ground plane makes the back lobe smaller.

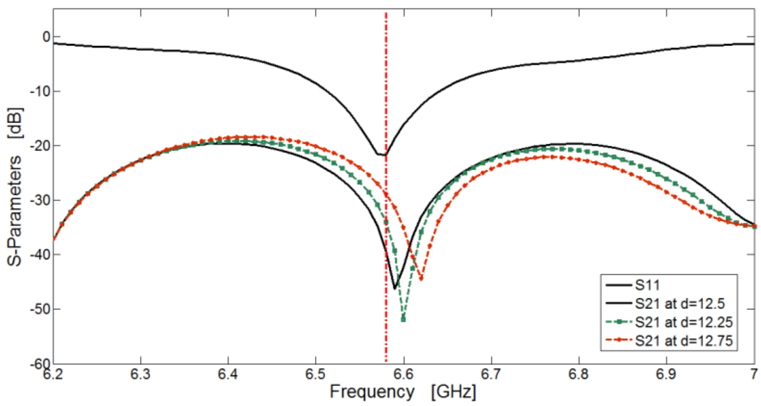


Figure 7.Simulated S-parameters (S_{11} and S_{21}) as a function of the distance between the CSSR.

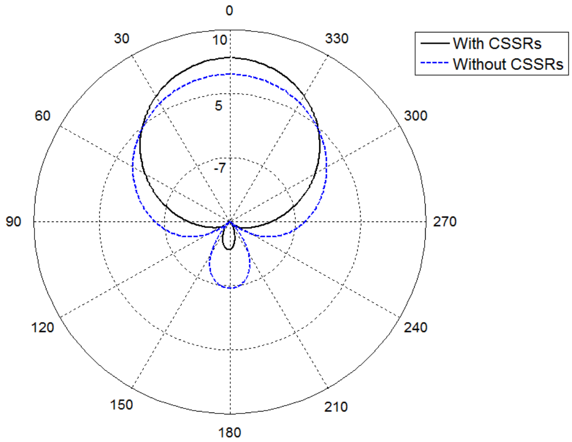
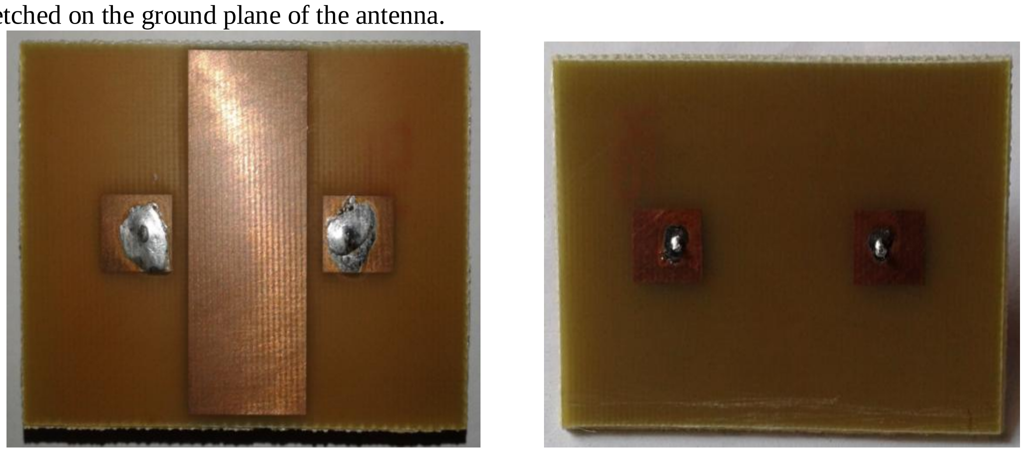


Figure 8. Simulation results for the far field gain patterns for the two patches with and without CSSRs resonators at 6.58 GHz.

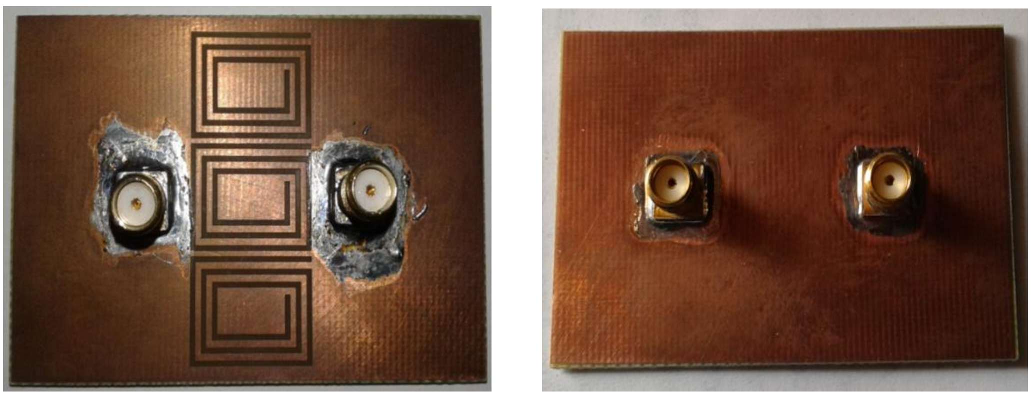
V. Experimental Results

Fig.9 showsthe photograph of the fabricated prototypelow profile antenna system (a)top view of the two patches without floatingground plane,(b)top view of the two patches with floatingground plane. Fig. 10 shows the bottom view of the antennasystems (a) with solid ground plane (without CSSRs structures), (b) with CSSRs etched on the ground plane of the antenna.



(a) (b)

Figure 9.The photograph prototype of the top view,(a) withoutflaoting ground and (b) with floating ground.



(a) (b)

Figure 10.The photo of the bottom view,(a) with solid ground "without CSSRs" and (b) with CSSRs etched in the ground plane.

In Fig. 11, the comparison between the simulated results of the proposed antenna without three complementary split spiral resonator and measured results is shown. Fig. 12 shows the comparison between the simulated results of the proposed antenna with three complementary split spiral resonator and measured results.

Fig. 13 shows the measured results of the proposed antenna without the three complementary split spiral resonators(CSSRs). Fig. 14 shows the measured results of the proposed antenna with the three complementary split spiral resonators(CSSRs).

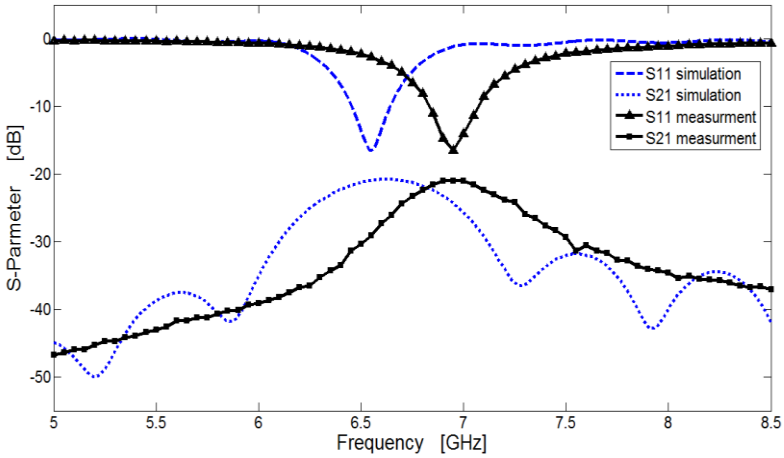


Figure11.Comparison between the simulated and measured results of the proposed antenna without three complementary split spiral resonators (CSSRs).

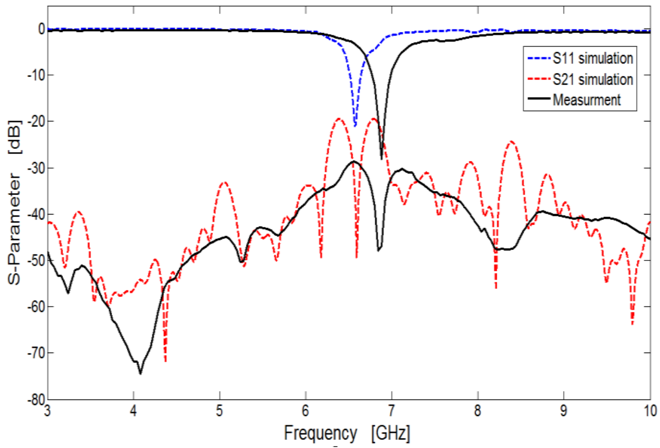


Figure 12.Comparison between the simulated and measured results of the proposed antenna with three complementary split spiral resonators (CSSRs).

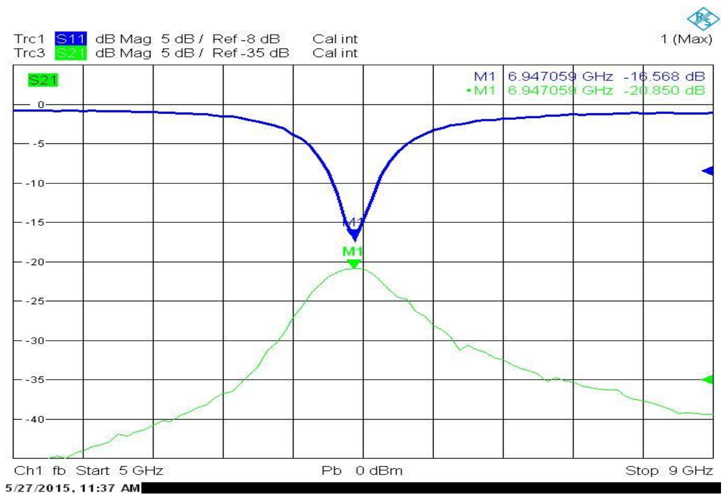


Figure 13. The measured results of the proposed antenna without the three complementary split spiral resonators(CSSRs).

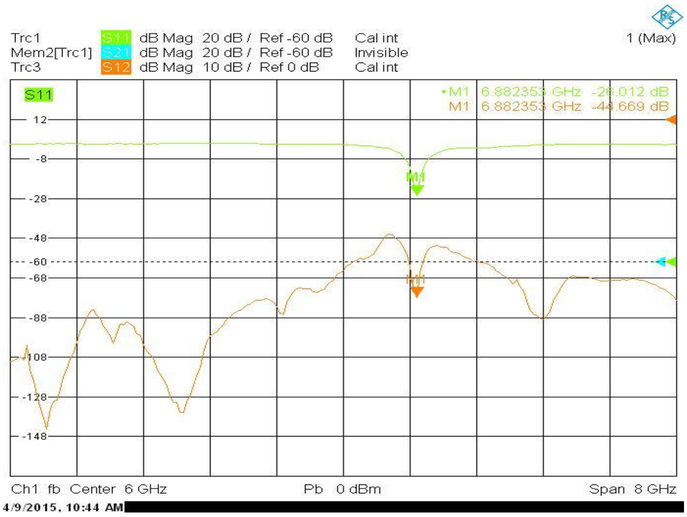


Figure 14. The measured results of the proposed antenna with the three complementary split spiral resonators(CSSRs).

VI. Conclusion

In this paper, the complementary split spiral resonators (CSSRs) have been used to reduce the mutual coupling between two patch antennas working at a frequency of 6.58 GHz. In the proposed antenna, mutual coupling reduction of 23-dB was achieved when three complementary split spiral resonators was used between two printed antennas. Ametamaterial MTM structures with negative permittivity were used for coupling reduction between array elements. The structures block the EM waves in one direction and guide it in the other direction. Also, it has been noticed that the positioning coordinates of the 3-spiral resonators relative to each other and relative to the two patches have a high effect on the final results.The antenna was designed using CST 2014 software, fabricated and measured.

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