FLEXIBLE COMPACT MIMO T-SHAPE ANTENNA WITH BRIDGE SQUARE SPLIT-RING RESONATOR

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***Abstract*— A flexible compact Multi-input Multi-output (MIMO) T-shape monopole antenna with negative permeability (MNG) unit cell working at 4.9 GHz is presented. The proposed printed monopole antenna is suitable for homeland security, public safety service, personal area network (PAN) and WLAN/On-Scene Incident command applications. MNG unit cell is integrated with the structure to decrease the mutual coupling effect inherent with MIMO system. The achieved results show that there is a good enhancements in mutual coupling reduction -11.1 dB and boresight gain 2.2 with 14.1% impedance bandwidth and 70.7% efficiency for 0.29λ as a separation distance between the MIMO antennas.**

***Index Terms*— Flexible compact MIMO, printed monopole, Metamaterial, μ-Negative.**

I. Introduction

Wireless is one of the most rapidly area of development technologies worldwide, however, these developments produce many challenges in communications field such as limited power, bandwidth as well as signal-to-noise ratio degradation caused by the surrounding environment [1]. MIMO system is based on using more than one antenna in the transmitter and the receiver sides consider a good solutions for the aforementioned challenges. This technique is mainly based on the theoretical work developed by Teletar and Foschini [2]. MIMO systems have been one of the most hot-spot of research and development areas in the broad field of wireless communications. A considerable efforts have been conducted in this area, leading to many immediate applications and to future ones [1].

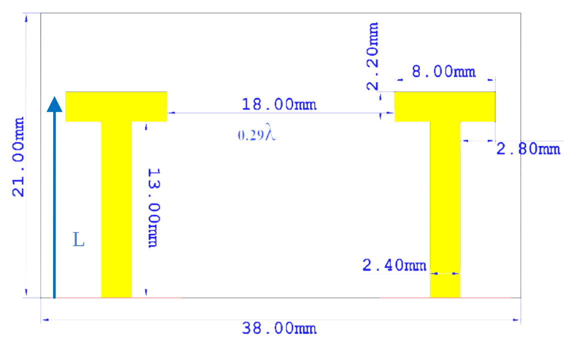
However, the MIMO system suffer from inherent problems and the important one is the mutual coupling. This challenge can be resolved by increasing the distance between the antennas, but, that will lead to enlarge the overall size of the system which may be unacceptable for many applications. There are many technologies have been proposed to solve this problem and with the same time keep it with a suitable size such as adding parasitic elements, Networks coupling, the neutralization line [3], defected ground planes [4], soft surfaces [5], 180° hybrid couplers [6], and metamaterial. The term “metamaterial” had been originally employed to describe any artificial (engineered) structure possessing effective electromagnetic properties not encountered among natural materials [7], metamaterial has been used in many applications including perfect lenses, artificial dielectrics and magneto-dielectrics, the LC-loaded transmission line and high impedance surface which include artificial magnetic conductor (AMC) and electromagnetic band gap (EBG) structure [7]. The MNG, as a one class of metamaterial is used in this paper to reduce the effects of the mutual coupling among adjacent MIMO antenna elements in a handheld device. MNG unit cell allows the possibility of synthesizing a magnetic material with positive or negative permeability in microwave region and the most important application for MNG is to prevent surface currents from flow between the contiguous antennas as in [8].

The simulation of the proposed structure is done by using computer simulation technology (CST) 2015 [9]. The fabrication of the prototypes is performed in the printed circuit laboratory of the department of electrical Engineering, College of Engineering, University of Basra, Iraq and the results showed decreased mutual coupling between the antenna elements by using the proposed MNG unit cell while preserving acceptable results for reflection coefficient and gain.

The paper is outlined as follows: section II illustrates antenna design, the MNG unit cell design and test is discussed in section III. Section IV presents the Flexible MIMO with the MNG unit cell fabrication while section V shows the practical and simulation results. Bending test is discussed in section VI and the paper ends with section VII which summarizes the main conclusions.

II. ANTENNA DESIGN

T-shape monopole type is adopted to design MIMO antenna. The monopole antenna possess many attractive properties compared to the patch antenna, such as Omni-direction, large impedance bandwidth, and high efficiency [10]. Roger 5880 material with dielectric constant 2.2 and loss tangent 0.0009 is chosen as a substrate due to its flexibility properties and its availability in the printed circuit lab. The proposed antenna printed on (38 mm x 21 mm) substrate with a thickness of 0.8 mm and fed by a microstrip transmission line with partial ground plane to increase the bandwidth of proposed antenna as depicted in Fig. 1.



(a)

(b)

Fig. 1. Proposed antenna array geometry and dimensions. (a) Front face (b) Back face.

The above design has been obtained through simulations and parametric study using CST Microwave Studio which it is based on calculating the effective radiating element L in term of guided wavelength λ_g:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{1}$$

where ε_{reff} is the effective relative dielectric constant, a value for the effective relative dielectric constant ε_{reff}, with a feed line width (W_f) to the substrate with height ratio $W_f/h \geq 1$, by means of Equation (1) as in [11]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12\,h}{w_f}}}\right) \tag{2}$$

The reflection and transmission coefficients as well as the radiation patterns of the proposed antenna are depicted in Figs. 2, 3, respectively.

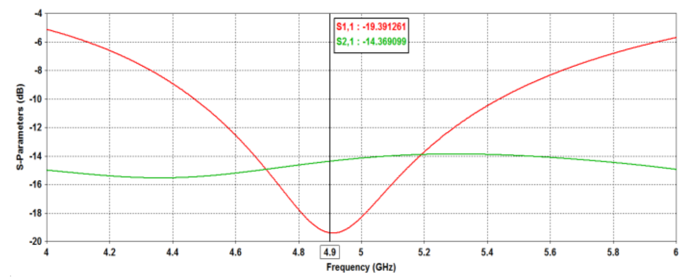
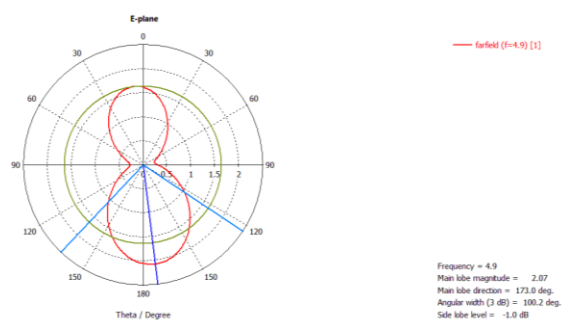
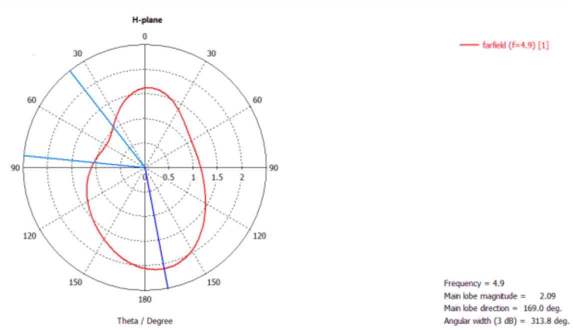


Fig. 2. Reflection and transmission coefficients (S_{11}, S_{21}).



(a)



(b)

Fig. 3. Radiation pattern. (a) (E-field). (b) (H-field).

III. MNG DESIGN

Numerous Split ring resonators (SRR) have been reported since its original conception by Pendry in 1999 [12]. This paper presents a design of Square Spilt-Ring Resonator (S-SRR) by connecting two S-SRR unit cells with a bridge. The unit cell has been called Bridged Rectangular Spilt-Ring Resonator (BS-SRR). The most important point in designing the SRR is producing a μ-negative over a certain bandwidth around the desired operating frequency of the antenna [13]. This can be achieved by choosing the proper dimensions of the BS-SRR unit cell for the allocated frequency band. The proper dimensions of the MNG are obtained through a parametric study and simulations based on the MNG equivalent circuit depicted in Fig. 4. and equations illustrated below [14]:

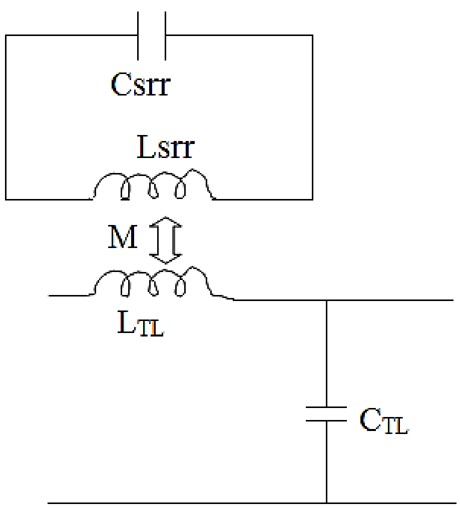


Fig. 4. Structure of the equivalent circuit of the SRR in the waveguide.

$$W_0 = \frac{1}{\sqrt{L_{srr}\, C_{ssr}}} \qquad (3)$$

L_{srr} and C_{srr} is the SRR parallel inductance and capacitance of the MNG unit cell which can find as [11]:

$$C_{srr} = (2r_{av} - \frac{g}{2})C_{pel} + \frac{\varepsilon_0 c*h}{2g} \qquad (4)$$

where, r_{av} is the average dimension of S-SRR, g spilt gap, h dielectric substrate thickness, c the conductor thickness and C_{pel} is the capacitance per unit length equal to:

$$C_{pel} = \frac{\sqrt{\varepsilon_r}}{c_0 * Z_0} \qquad (5)$$

where Z_0 is the characteristic impedance of the line and c_0 is the velocity of light in free space.

$$L_{srr} = 0.0002l\left(2.303\log_{10}\frac{4l}{c} - 2.853\right)\mu H \qquad (6)$$

where l is the wire length. The length l and thickness c are in mm.

For the center frequency of 4.9 GHz, the proper dimensions of the MNG are depicted in Fig. 5.

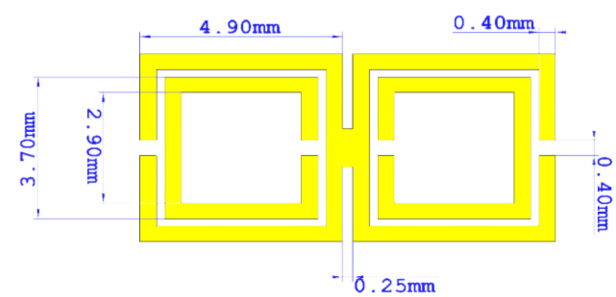


Fig. 5. Schematic of the MNG unit cell dimensions.

MNG metamaterial structures are sensitive to the orientation of the impinging magnetic field. Perfect Magnetic Conductor (PMC) boundary conditions are assigned to the top and bottom of the waveguide while Perfect electric conductor (PEC) is used as side walls to enforce the TEM mode with the magnetic field vector normal to the plane of MNG unit cell as illustrated in Fig. 6

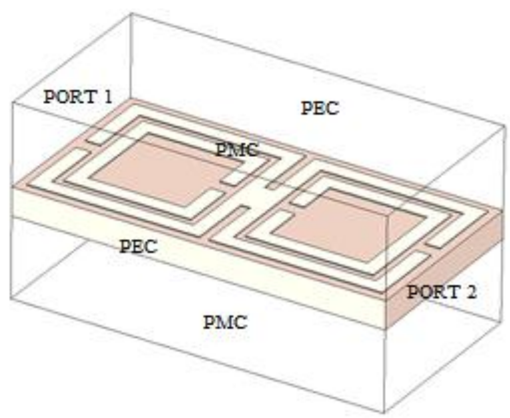
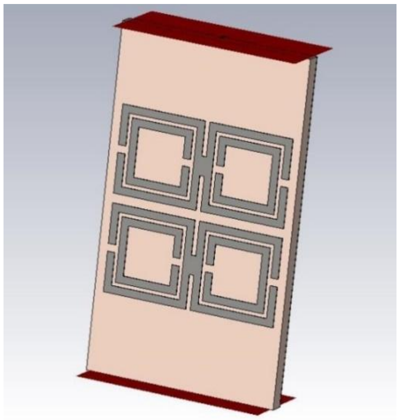


Fig. 6. Boundary conditions used to characterize the MNG unit cell.

Testing of the designed MNG unit cell with an ungrounded substrate is performed using the transmission line method and the aforementioned method to obtain S_{11} and S_{21} parameters which are illustrated in Fig. 7, 8.



(a)

(b)

Fig. 7. Transmission line method. (a) Front face. (b) Back face.

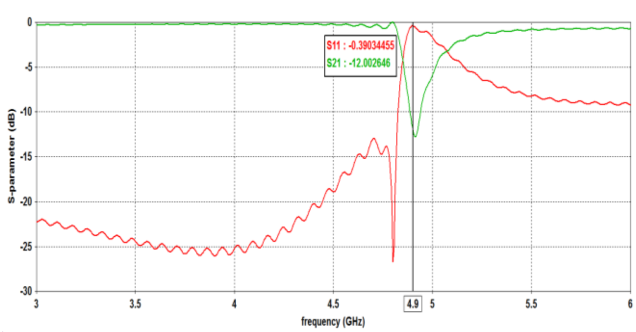


Fig. 8. Simulated $S_{11}$and S_{21} parameters versus frequency.

Then, these parameters are used to retrieve value of the μ by method reported in [15]. The achieved values of μ are listed in Fig. 9.

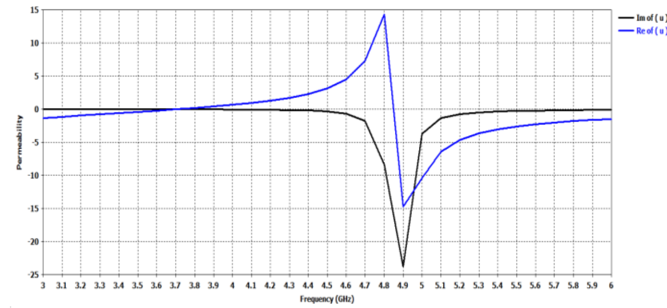


Fig. 9. Effective complex permeability values of the BS-SRR unit cell.

IV. ANTENNA FABRICATION

The radiating element with ground plane are printed on the both side of 0.8 mm Roger 5880 substrate by using Protomat S42 machine. Then, an SMA connector was fixed to each radiating element and the partial ground on the other side to achieve the aimed goals as illustrated in Fig. 10.

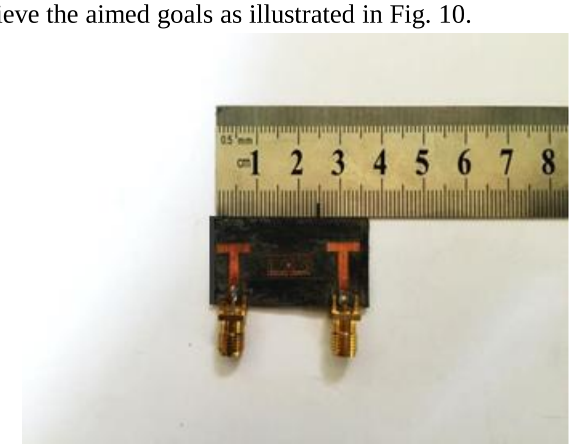


Fig. 10. Antenna prototype.

IV. SIMULATION AND MEASURED RESULTS

The fabricated antenna is connected to the microwave signal analyzer, model Ametic- MSA10 with 0.04-12.4 GHz and calculate the reflection and transmission coefficients S_{11} and S_{21}. The results are shown in Figs. 11, 12, respectively. There is a good agreement between the simulation and practical measurement of S_{11} and $S_{21.}$

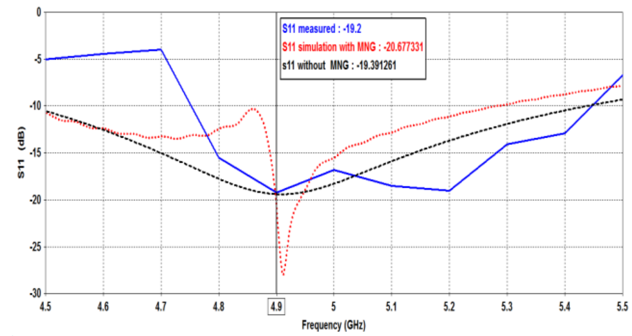


Fig. 11. Measured S_{11} with and without including the MNG .

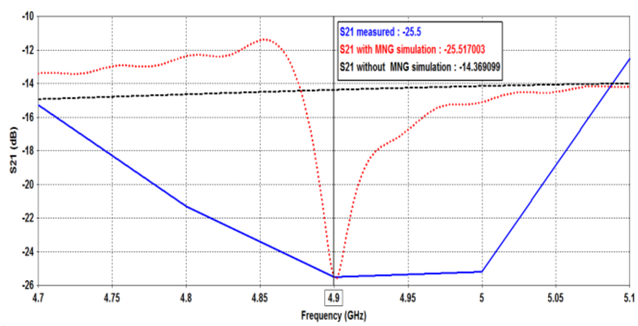


Fig. 12. Measured S_{21} with and without employing the MNG.

Fig. 13 illustrates the realized gain after inserting the MNG in the final structure. The simulation efficiency after adding the MNG is 70.7% as depicted in Fig. 14.

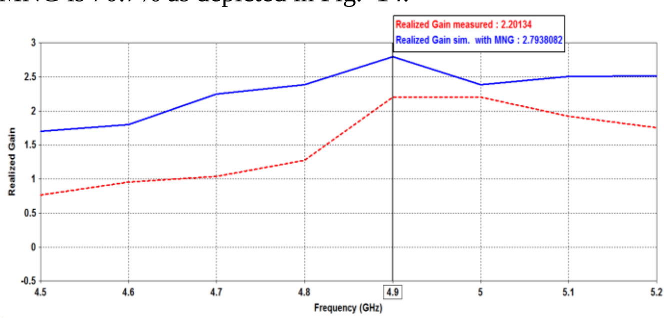


Fig. 13. Measured and simulated realized boresight gain with MNG.

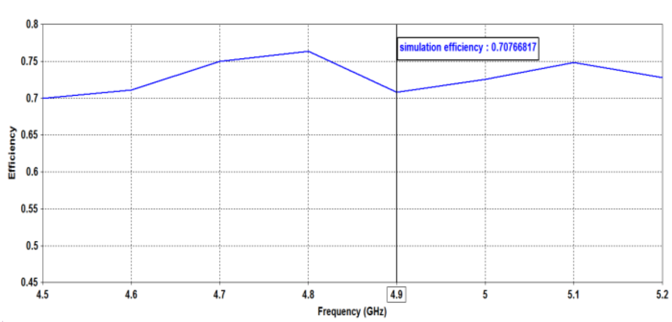
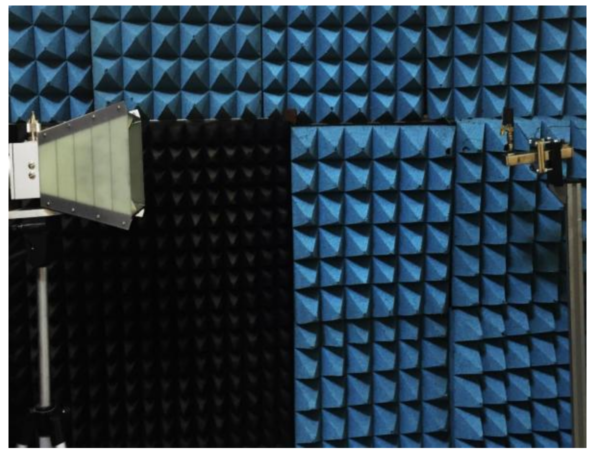
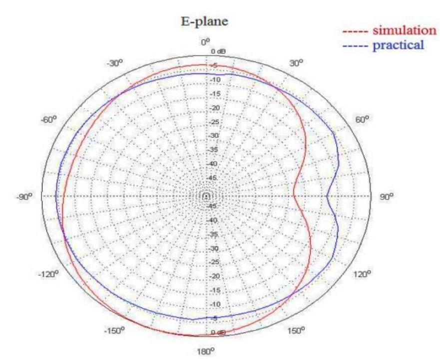


Fig. 14. Total Efficiency simulation with using the MNG.

The far-field radiation patterns in the E-plane and H-plane are measured inside the College of Engineering, University of Basra anechoic chamber. The fabricated antenna was placed on steeper motor controller holder, model Ametic SMC 10 and aligned to a reference horn antenna with a modifiable polarization where E and H planes cuts can be obtained. Radiation patterns of the fabricated antenna at 4.9 GHz in the YZ plane (E-plane) and XZ plane (H-plane) are depicted in Fig. 15. It can be noted that the antenna have radiation pattern close to Omni-directional at resonance frequency.



(a)



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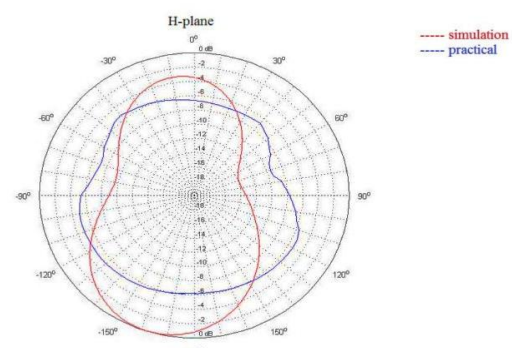


(c)

Fig. 15. (a) Measured normalized radiation pattern. (b) YZ (E-plane). (c) XZ (H-plane).

This design has a very good simulated envelope correlation coefficient. The MNG reduced the envelop correlation from 0.00093 to 0.0001, as depicted in Fig. 16.

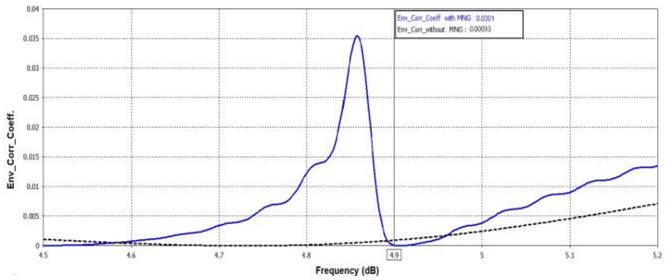
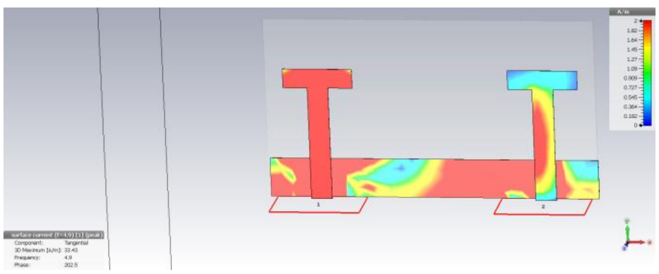
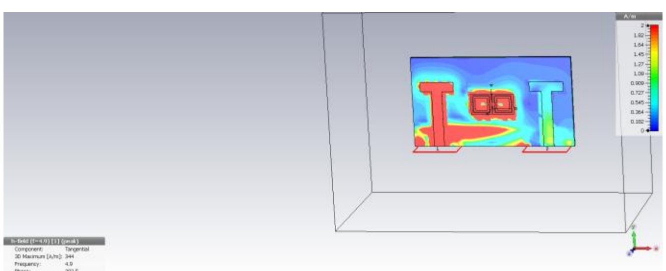


Fig. 16. Envelope correlation coefficient with and without using the MNG.

Fig. 17. presents results for the surface current of the antenna. Fig. 17-a illustrates the results without the MNG while Fig. 17-b shows the influence of the MNG. It is clear that the MNG plays an important role in reducing the surface current induced on the antenna that is not excited.



(a)



(b)

Fig. 17. Current surface of the proposed antenna. (a) without using MNG. (b) with using MNG.

VI. FLEXIBILITY TEST

Since the proposed antenna may be experience bent or conform during operation flexibility tests are accompanied to ensure performance reliability. Resonant frequency and return loss need to be calculated since they are prone to shift/decrease due to impedance mismatch and change in the actual electrical length of the radiating element [16].

The test done by bending the proposed antenna over cylindrical foam with raids of 13 mm and then calculate the reflection coefficients by using microwave signal analyzer as depicted in Fig. 18.

Fig. 18. Measurement for the flexibility.

The results show that the values of S_{11} and S_{21} are not significantly influenced by bending the designed structure as depicted in Figs. 19, 20, respectively.

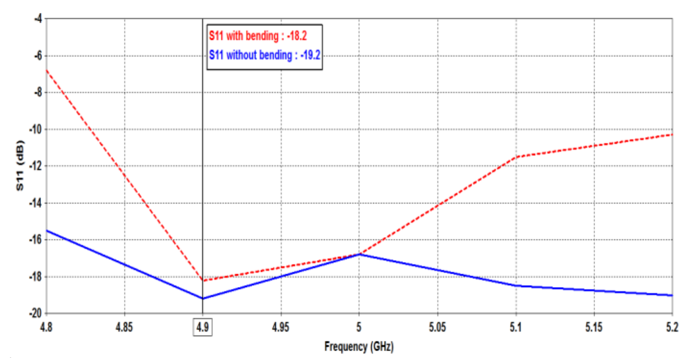


Fig. 19. S_{11} with and without bending.

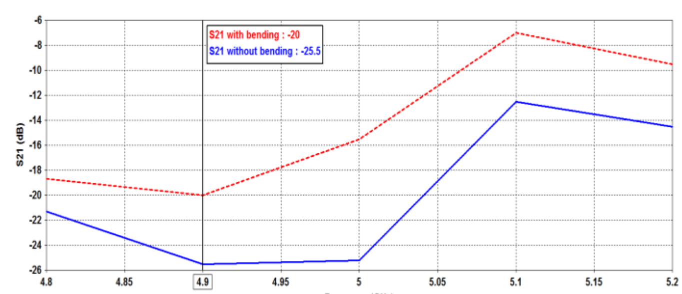


Fig. 20. S_{21} with and without bending.

VII. CONCLUSIONS

A flexible compact MIMO (2 x 1) T-shape monopole antenna with MNG unit cell is designed and fabricated. The MIMO system works at frequency 4.9 GHz with bandwidth of 695 MHz and boresight gain of 2.2 dB. A new shape of the MNG is used to decrease the mutual coupling. The MNG designed and tested, then integrated with the MIMO antenna array which it printed on a (38 mm x 21 mm) Roger 5880 with a thickness of 0.8 mm. The results show good agreement between the simulations and measurements results.

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