Design and Implementation of Closely Spaced MIMO Antennas Zeroth-Order Resonator Antenna (ZORA) with Enhancement Isolation

Ahmed M. Annekaa[1], Abdulgader Z. Abdalla[2]
[1]Communications & Microwaves Department. College of Electronic Technology.Bani Walid Libya, ahmedgrera88@gmail.com
[2]Communications & Microwaves Department. College of Electronic Technology.Bani Walid,Libya, azazgbwl@yahoo.Com

Abstract— **A high isolation multiple-input multiple-output (MIMO) antenna with closely spaced was presented. This antenna was designed for the purpose of MIMO wireless application. The proposed MIMO antenna consists of two antennas, each operates at 2.5 GHz. The MIMO antenna system elements on a single low-cost FR4 substrate of a compact size of 47.36 mm × 29 mm and is fed by a 50 Ω microstrip. A prototype band WiMAX antenna performance was examined. The results showed that the antenna has at 2.5 GHz a reflection coefficient better than -40 dB. As a new approach, the reduction of mutual coupling depends on current cancellation between two antennas. The proposed antenna achieved better than -30 dB isolation between the two inputs. In addition, high isolation between the antenna elements and the small spacing between antenna elements, the proposed antenna has compact size reduction of approximately 60% compared to conventional patch antennas operating at the same frequency.**

Index Terms- multiple-input multiple-output antenna (MIMO), reflection coefficient (S11), Composite right/left-handed (CRLH).

I. Introduction

Multiple-Input Multiple-Output (MIMO) system utilizes multiple antennas to increase channel capacity without sacrificing additional spectrum or transmitted power. The transmitted power has received a growing amount of interest in recent years. MIMO antenna technology can provide higher receiver gain, in- creased data rates, larger network throughput, and improved reliability through antenna diversity. However, to achieve these advantages, the MIMO antenna is required to have low mutual coupling between closely packed antenna elements, which is quite difficult to realize using the limited spaces of the handsets. Recently, there have been efforts on research in attempt to reduce the mutual coupling between elements in MIMO antennas. The MIMO antenna was designed by using microstrip antenna because microstrip patch antenna is one of the most preferred antennas due to its low cost, light, weight, simple implementation process and conformability. The microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. However, the general microstrip antennas suffer from narrow bandwidth, one of the applications of microstrip antenna for MIMO wireless applications.

Presently, wireless applications are quickly moving towards multiple input multiple output (MIMO) configuration, thereby the quest for integration of many antennas in the user's equipment has been enhanced. MIMO technology, which uses multiple antennas, has become a very promising technique for enhancing the performance of wireless communication systems. A MIMO antenna is used as a reason of enhancing the capacity of the channel without the need of additional power or frequency band. It requires many antennas set up in the transmitter with less coupling between them. Hence, for an effective MIMO antenna system mutual coupling between the antennas should be low. Mutual coupling is defined as the interaction of electromagnetic field between the antenna elements. Various MIMO antenna designs have been reported by antenna researchers for wireless applications. The main design challenge in MIMO antennas is to attain high isolation amid the antenna elements.

The wireless multimedia technology has increased the capacity and reliability requirements of wireless communication systems. Therefore, the MIMO system has been one of the most suitable and promising technology. Therefore Several works have been conducted to reduce the mutual coupling effect between antenna elements in MIMO systems such as using electromagnetic band gap (EBG) structures. For example, EBG structures with insertion of vias have been applied to reduce the mutual coupling of the microstrip phased array antennas [1]. These structures are complex to be designed, as well as they occupy a comparatively large area. Defected ground structures (DGSs) are implemented by etching slots of different shapes in the ground plane, which exhibit miniature size compared to EBGs. A successful example is a design of two patch antennas with separation distance between the centers of these patches equal to $\lambda_0/2$ was presented [1] .The reduction of mutual coupling was achieved by using defected ground structure which achieved low mutual coupling; up to -37dB. However, the size of such techniques is still very large, especially for compact antenna applications. Left handed (LH) transmission line (TL) is characterized by anti parallel phase and group velocities. Also, it has a non linear

Received July 2019, Received in received from October 2019, Accepted November 2019, and Published July2020

progressive phase [1]. Because of these properties, compact microwave devices such as power dividers, filters, phase shifter, resonators, and antennas have been introduced. Compact and multi bands antennas including novel zeroth order resonator antenna (ZORA) are presented for different wireless applications [2].

In this paper, a MIMO antenna with small size and high isolation is presented for wireless application (WiMAX applications), The proposed MIMO antenna has two elements with a small size and very low mutual coupling, each of which consists of two meandering strips located at a FR4 substrate with the dielectric constant of 4.4. The MIMO antenna covers the bandwidths of 2.5 GHz (WiMAX). The designed results were validated by using the electromagnetic full wave simulations.

II. DESIGN OF A INTERDIGITEL MICROSTRIP ANTENNA

Unit Cell Model

By working with the Equivalent Circuit Model of a Microstrip CRLH Transmission Line, we made the calculation for our antenna in this section as shown Fig. 1, Fig. 2. [3].

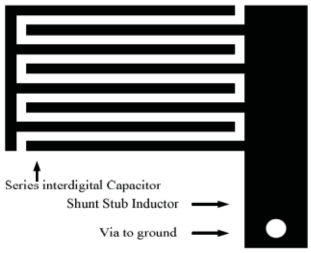

Fig. 1. Unit Cell Model CRLH Transmission Handed.

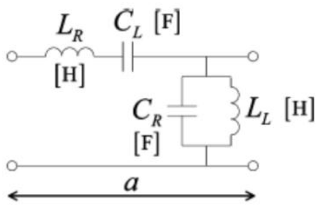

Fig. 2. Equivalent Circuit Model of Microstrip Composite Right/Left Handed TL.

The calculations of the initial unit cell model design for the ZORA Antenna design. The layout was adjusted multiple times to get the desired result as shown Fig. 3.

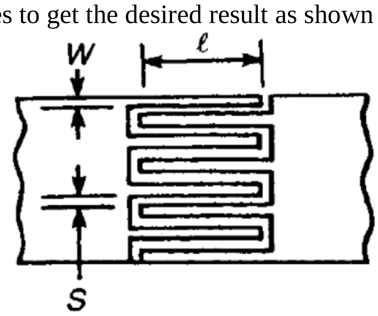

Fig. 3. Layout of the Interdigital Capacitor [3].

where

l: Finger Length (mm)

W: Width of the Microstrip Line (mm)

S: Spacing between Fingers

N: Number of Fingers

ε_e : Dielectric Constant of Microstrip Line

h: Height of the Dielectric Substrate.

To calculate the Interdigital Capacitor values, we use the equations in [7] section (3.2).

$$C(pF) = \frac{\varepsilon_e 10^{-3} K(k)}{18\pi K'(k)}(N-1)l \quad (1)$$

where:

$$k = tan^2\left(\frac{a\pi}{4b}\right) \quad (2)$$

$$a = W/2 \quad (3)$$

$$b = (w+s)/2 \quad (4)$$

$$K' = \sqrt{1-K^2} \quad (5)$$

$$\varepsilon_e = \begin{cases} \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W}}} + 0.04\left(1-\frac{W}{h}\right)^2\right] & for\ \frac{W}{h} < 1 \\ \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) & for\ \frac{W}{h} > 1 \end{cases} \quad (6)$$

The configuration of the optimization proposed interdigital antenna is shown in Fig. 4. As shown in the Fig. 4, the antenna was designed and printed on a FR4 substrate with relative permittivity 4.4 and a thickness of 1.6 mm, connected to a 50 Ω feeding line. The single element antenna was designed to operate at 2.5 GHz. The simulation is done using HFSS software. The geometric parameters were adjusted carefully and final optimized antenna dimensions are shown in table 1 [2].

.

Table 1. The dimension of Unit Cell Model Antenna.

Antenna Model	**Parameters [mm]**					
Unit Cell Model	*L*	*S*	*A*	*B*	*C*	*D*
	4.65	0.2	1.4	16.2	4.2	12.65

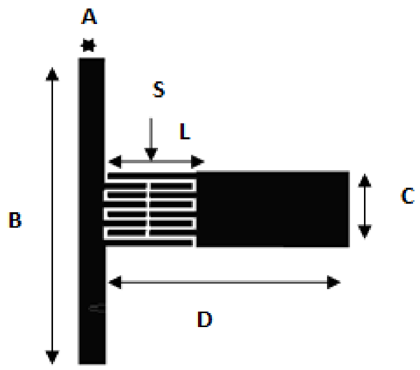

Fig. 4. Layout of single-element CRLH antenna.

After the simulation and the optimization using HFFS Software, the final dimensions are shown in the Fig. 5.

Received July 2019, Received in received from October 2019, Accepted November 2019, and Published July2020

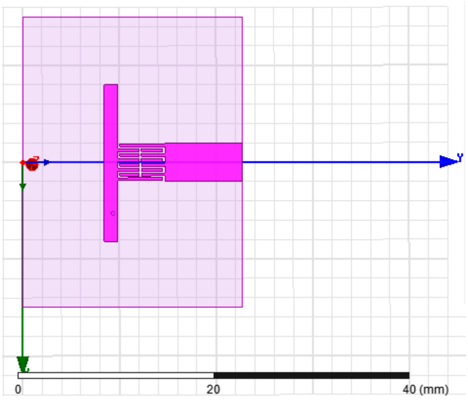

Fig. 5. Geometry structure of proposed single-element CRLH antenna in (mm).

III. SIMULATION RESULTS

The design of the proposed antenna was done by the proper selection of the loading left-handed elements. This was checked by using electromagnetic full wave simulation (HFSS) and experimentally confirmed. First we exanimate RL. The difference between return loss (RL) and the reflection coefficient S_{11} is very minor. RL in dB is $RL = 10log_{10}(P_i/P_r)$, where Pi and P_r are the incident and reflected powers, respectively. S11 in dB is $S_{11} = 20log_{10}|E_r/E_i| = 10log_{10}|E_r/E_i|^2 = 10log_{10}(P_i/P_r)$, where E_r and E_i are the reflected and incident fields, respectively. In general, S_{11} is a complex quantity and the relationship between RL and S_{11} is hard to discern. Thus, from the above analysis, $RL = -S_{11}$.

Simulation results for reflection coefficient S_{11} values for single antenna are illustrated in Fig. 6. The geometry of antenna designed simulation is performed. At the resonant frequency of 2.5 GHz, the design is simulated in the frequency range of 2.4 to 2.55 GHz (under -10 dB) with - 23.5 dB centered on 2.5 GHz. As shown in Fig. 6, it is quite clear that this operating band meet the design requirements of 2.5 GHz (WiMAX standard operating frequency).

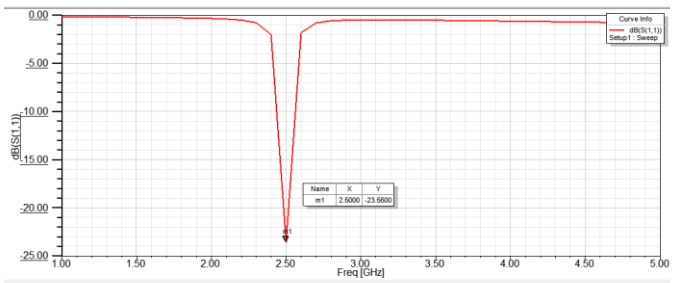

Fig. 6. Return loss Vs. Frequency plot of single CRLH antenna.

IV. MIMO ANTENNA SYSTEM

The development of wireless communication system begins with the inception of the single input/single output antenna system (SISO) that consists of a single antenna to transmit the signal to the transmitter and receives the signal from a receiver. Further development saw the birth of smart antenna system. A smart antenna system may be categorized into a single input/multiple output (SIMO) and a multiple input/single output (MISO). There is an insatiability demand for high data rate, high link quality and large bandwidth antenna for both the transmitter as well as the receiver. These criteria may be achieved by the inclusion of more than one antenna through MIMO technology. The basic idea of MIMO system is to improve quality (BER) or data rate (bits/s) by using multiple TX/RX antennas. MIMO technology using multiple antennas for both transmitting and receiving end of the communication system is considered as one of the most promising approaches to reach higher data rate in rich scattering environment [4]. The basic notion of the SISO, SIMO, MISO and MIMO are illustrated in Fig. 7.

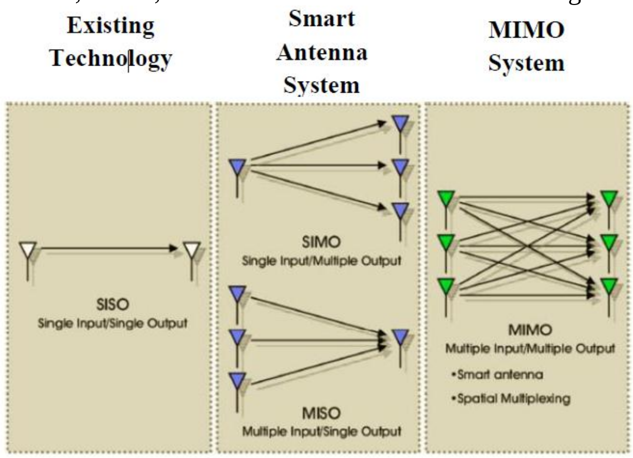

Fig. 7. Basic model of SISO, SIMO, MISO and MIMO [2].

MIMO technology exploits multipath to provide higher data throughput and simultaneously increases its range and reliability without consuming extra radio frequency. MIMO can be implemented through beamforming, spatial multiplexing and diversity techniques [5]. By introducing multiple antennas at both transmitter and receiver side, the diversity is achievable. The channel capacity, bandwidth and data rate increases automatically without increasing the transmitting power signal. The MIMO concept is depicted in Fig. 8

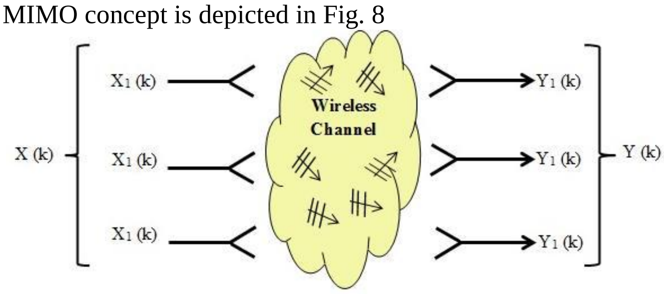

Fig. 8. The MIMO system concept.

A major challenge in designing a MIMO antenna is the mutual coupling. Mutual coupling is the electromagnetic interaction between antenna elements due to the small space of the antenna element. The performance of the MIMO antenna system such as lower correlation coefficient and higher antenna efficiencies are often influenced by low mutual coupling.

In MIMO applications, the signals transmitted by multiple antenna elements are generally considered to be independent or uncorrelated. However, in reality, the current induced on one antenna produces a voltage at the terminals of nearby elements that is characterized as mutual coupling [6]. The port to port isolation defined as the transmission power between two of the input ports of the multiport antenna under test. It is characterized by |S21| parameter.

Received July 2019, Received in received from October 2019, Accepted November 2019, and Published July2020

MIMO system requires the |S21| to be minimized as low as possible, as isolation is directly related to the antenna efficiency.

$$\text{Isolation} = -10 \log_{10} |S21|^2 \qquad (7)$$

V. DESIGN AND IMPLEMENTATION OF CRLH MIMO ANTENNAS WITH HIGH ISOLATION

The two designed elements in MIMO antenna are put together on the same FR4 substrate as shown in Fig. 9. The design objective of this MIMO antenna was based on achieving two antennas operating at 2.5 GHz with very close distance and high mutual coupling isolation without the use of any extra structure. The final MIMO antenna layout in Fig. 9, indicates that the overall length of the antenna is 47.36 mm, the width is 29 mm, and the separation distance between the two antennas is only equal to 0.15ʎ.

The design starts with the previously introduced single element antenna and some fine optimization tuning were done for better coupling reduction.

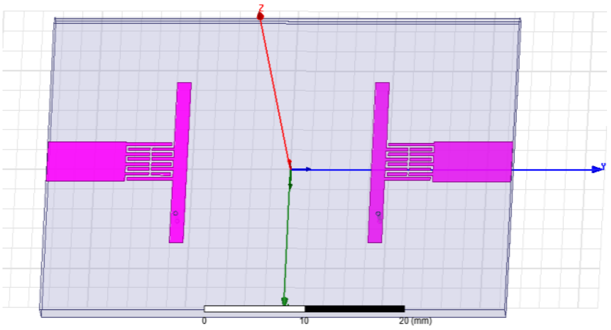

Fig. 9. layout of CRLH MIMO antenna

VI. SIMULATION RESULTS OF MIMO ANTENNA.

A- Antenna reflection coefficient

The simulated reflection coefficient versus frequency is shown in Fig. 10, As shown in this Fig. 10, we can observe that this approach can achieve an ultra-wide bandwidth characterized with low reflection coefficient. It is clear that the antenna has the resonant frequency of 2.5 GHz with - 46 dB in the frequency range of 2.3 to 2.6 GHz . it is also clear that reflection coefficient is lower than -10 dB.

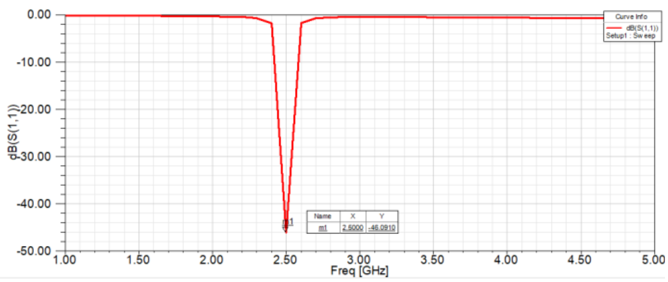

Fig. 10. Simulated return loss (S_{11}) for the proposed two elememt MIMO antenna at 2.5 GHz

B- Coupling between two elements.

A final result of microstrip patch antenna was optimized for return loss and mutual coupling. From Fig. 11, it could observed that return loss (S_{11}) value was met the desired value (< -10dB) which was centered at 2.5 GHz with -46 dB, bandwidth which extends from 2.3 GHz to 2.6 GHz. This means that the antenna operates at WiMAX band. However, the mutual coupling (S_{21}) has a high value of -30 dB at 2.5 GHz, also from Fig. 12, it could also be observed that return loss (S_{22}) value has met the desired value (< - 10dB) which was centered at 2.5 GHz with -39.6 dB, bandwidth which extends from 2.3 GHz to 2.6 GHz. However, the mutual coupling (S_{12}) has a high value of -30dB at 2.5GHz, which is good isolation without using any extra structure as DGS or EBG.

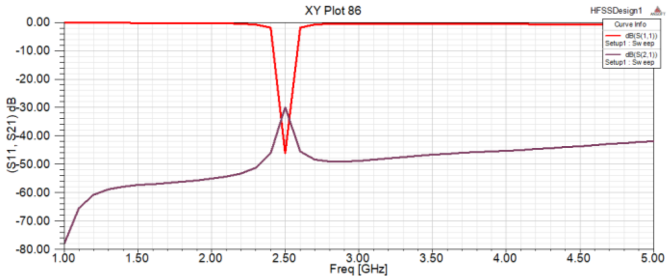

Fig. 11. Scattering parameter magnitudes (S11-S21) of two-element CRLH MIMO antenna at 2.5 GHz.

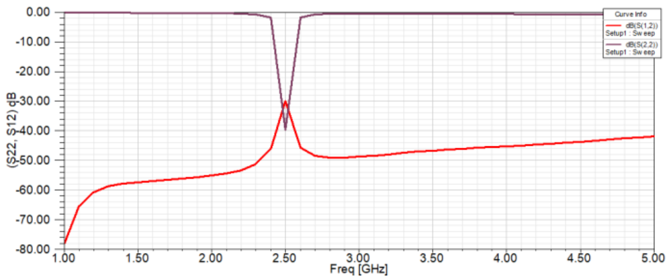

Fig. 12. Scattering parameter magnitudes (S22-S12) of two-element CRLH MIMO antenna at 2.5 GHz.

C- Radiation Pattern

Fig. 13, shows the simulated of 2D and 3D radiation pattern, xz-plane and yz-plane radiation pattern of the proposed antenna at 2.5 GHz. As shown in Fig. 13, the designed antenna displays good broadside radiation patterns in the xz-plane and yz-plane. The designed antenna radiation is 6.3 dB.

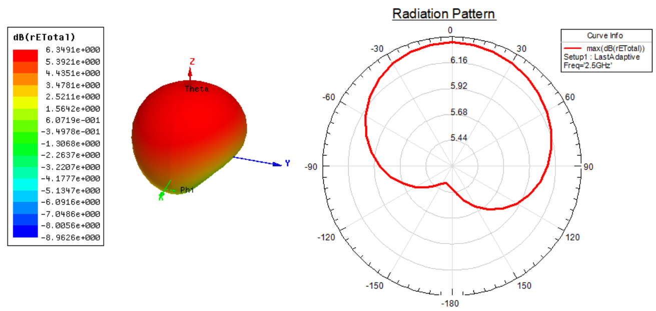

Fig. 13. 2D and 3D radiation pattern of the proposed CRLH MIMO antenna at 2.5 GHz.

D- surface current distribution

Fig. 14 and Fig. 15 shows the surface current distribution at 2.5 GHz, if Port 1 is excited and Port 2 is terminated with matched load of 50 Ω. When the Port 1 is excited, there is some amount of surface current present at port 2 through the common radiator and the ground plane. In order to reduce this surface current present at Port 2, it is obvious that the interdigital capacitor is responsible for radiation and the current is concentrated in the capacitor than

Received July 2019, Received in received from October 2019, Accepted November 2019, and Published July2020

stub. The two currents in the two capacitors are opposite in its direction, which reduced the coupling between the two antenna elements to lower level like DGS or EBG, which increase the dimension of the antenna. The surface currents are mainly confined in the interdigital slot at 2.5 GHz, which thereby significantly reduce the mutual coupling between the two ports, which means that the mutual coupling between them is increases, the same result has for port (2). When the Port 2 is excited then there is some amount of surface current present at port 1 through the common the radiator and the ground plane.

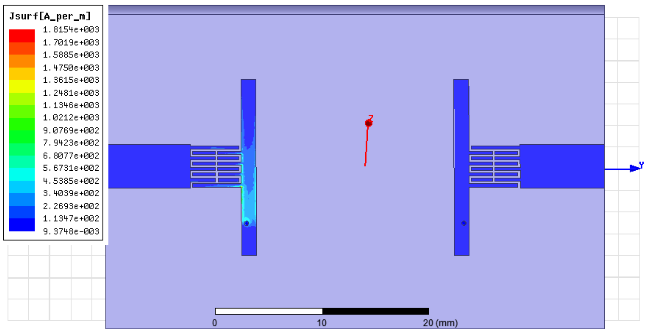

Fig. 14. Current distripution on CRLH MIMO antenna, at port 1.

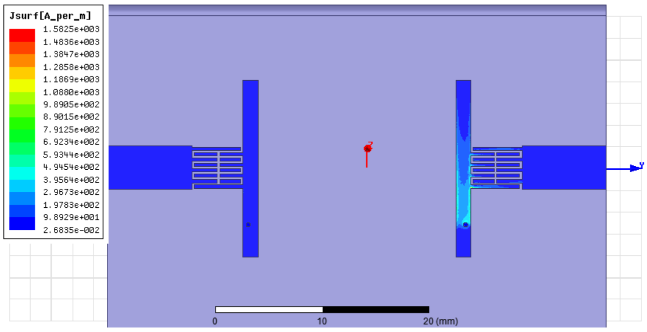

Fig. 15. Current distripution on CRLH MIMO antenna, at port 2.

IV. Conclusion

A MIMO antenna has been introduced. Two antennas have been designed and the results have been discussed. Good optimization, good matching and typical radiation pattern over the antenna MIMO have been reported. The results confirm a good compromise between reflection coefficient and radiation pattern that have produced frequency band from approximately 2.5 GHz with good matching characteristics. A MIMO antenna system with high isolation has been proposed and investigated. Good isolation performance has been achieved through the proposed shaped structure. The reflection coefficient S_{11} is –46 dB which indicated a good receiving signal and a radiation pattern 6.3 dB. The proposed antenna has the advantages of compactness (its size is only 47.36 X 29 mm^2) with closed spaced (0.15ʎ) which represents almost 60% size reduction. In addition, the designed antenna has better than -30 dB coupling isolation between the two ports at the operating frequencies. The orientation of interdigital capacitor has reduced the mutual coupling between two very closed antennas without using any extra structure as DGS or EBG.

References

[1] C. A. Balanis "Antenna Theory Analysis and Design", John Wiley & sons, inc., Publication, 3rd Edition, ISBN: 0-471-66782, 2005.

[2] M. Abdalla1 ,A. Ibrahim, A.Abdel-Rahman, Hesham F. A. Hamed, "Investigation Design of a High Isolation Closely Spaced Compact CRLH Meta-Material MIMO Antenna", 30thNATIONAL RADIO SCIENCE CONFERENCE (NRSC 2013) April 2013, National Telecommunication Institute, Egypt.

[3] C. Caloz, "Electromagnetic metamaterials", Wiiley, 2006.

[4] D. Gesbert, M. Shafi, D. Shiu, P. J. Smith, and A. Naguib, "From theory to practice: an overview of MIMO space–time coded wireless systems," IEEE Journal on Selected Areas in Communications, vol. 21, no. 3, pp. 281-302, 2003.

[5] "Understanding of SISO, SIMO, MISO and MIMO". Retrieved December 17, 2014.

[6] M. A. Abdalla1 ,. " Small Size High Isolation CRLH Meta- Material Closely Spaced MIMO Antenna"., 30th NATIONAL RADIO SCIENCE CONFERENCE (NRSC 2013).

[7] C. Caloz and T. Itoh, Electromagnetic Metamaterials Transmission Line Theory and Microwave Applications. Hoboken, NJ, USA: Wiley, 2006.

Received July 2019, Received in received from October 2019, Accepted November 2019, and Published July2020