A Systematic Review of Existing Methodologies, Tools, Materials and EM Solvers used in Design of MIMO Antennas for Wireless Applications

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Abstract— This article presents brief review of the articles reported by various researchers in the field of MIMO antenna design for wireless applications. Different tools and techniques adapted for design of MIMO antenna are described in this paper. Comparison of various methodologies of antenna design and different software tools used for simulation is done to propose powerful techniques to proceed in the field of Microstrip Patch Antenna design for implementation of MIMO systems. Antenna system with high data rate, high gain, wider bandwidth, improved signal quality, higher spectral efficiency, reduced mutual coupling, low cost and small size is the need of today's wireless communication engineering. Hence, overall objectives of this article is to summarize and study different shapes of MIMO antennas and compare different parameters of various designs of antenna such as Mutual coupling, Resonating Frequency, VSWR, Bandwidth, Data rate, Efficiency, Gain and Return Loss.

Keywords: MIMO Antennas, Microstrip Patch Antenna, Antenna Design and Simulations

I. INTRODUCTION

It is important to study powerful design methodology, different simulators and techniques to fabricate the MIMO antenna. Wireless communication systems such as WiFi, WiMax, LTE and many more technologies are becoming popular. Every wireless communication needs a transducer as a mean to convert electric signals to electromagnetic waves and vice versa. Transducers are generally in the form of antennas. Overall performance of almost all wireless communication depends upon efficiency of antennas used in it. Every antenna possesses characteristics viz., directivity, data rate, gain, bandwidth, signal quality, spectral efficiency, mutual coupling, cost and size. So various articles reported by different researchers are studied and compared all parameters targeted in those articles. Conclusion of this comparison is made based on Methodologies, Material and Software (s) used, Applications and results achieved by using different tools and techniques.

II. REVIEW OF LITERATURE

The two element slotted patch antenna designed and simulated for full ground and slotted ground. The result shows that at full ground the resonant frequency is 4.3 GHz and isolation and return loss is poor as compared to slotted ground which has return loss and isolation is more that -20 dB. At the same time the value of obtained gain is good of full ground antenna as compare to slotted ground. The surface current also compared for both cases. The ECC is also found good in slotted ground antenna as compare to full ground [1].

In [2], a single band MIMO antenna which operates from 2.3 GHz to 2.5 GHz is proposed which is not only used for WLAN application but also for other wireless application. Though the proposed antenna is just a single band antenna, it is an MIMO antenna which satisfies the demand for high data rates and spectral efficiencies when compared to conventional antenna. The structure of the proposed antenna is a bowtie antenna which is an advantage since it falls under the category of frequency independent antennas. The peak gain of the antenna is 1.6, making the antenna resonate at multiple frequencies may be the future works of the paper.

In [3], authors presented the design of a compact size modified rectangular shaped microstrip line feed with DGS patch antenna and their 2x1 MIMO implementation for wireless applications. The proposed antenna operate frequencies range 7.14-7.42GHz, 7.6-8.2GHz, 8.2-8.6GHz, 9.8-10.2GHz frequencies for VSWR≤2 study was performed to implement this antenna in 2x1 MIMO arrangements on the same circuit space. VSWR should less than 2, ECC less than 0.005; Mutual coupling should be less than -10dB. The proposed Antenna have Better mutual coupling and better envelope correlation coefficient are achieved.

Avery simple design of microstrip patch antenna with Double I slot at 8GHz has been designed and simulated. The effect of adding slots on resonance frequency and bandwidth and return loss has been showed. Different parameters of the designed antenna such as return loss, VSWR, radiation pattern and gain have been discussed. Bandwidth of the antenna can be increased by several ways such as increasing substrate thickness, adding slots. From the results this antenna serves wide band applications. The design of the rectangular patch antenna has been done using ANSOFT HFSS, MATLAB Program [4].

MIMO antenna systems will also be used for next generation wireless terminals, i.e. 5G and beyond. For every new wireless generation the data rates and channel capacities are growing. Hence, a very large leap is expected by the year 2020 where data rates in the ranges of tens of gigabits per second are expected from mobile terminals and other compact devices. In this paper, a novel compact two element MIMO array is developed resonating at 5.4 GHz with a reduced mutual coupling of –31 dB. These characteristics are well suitable for MIMO applications, using which high data rates can be obtained. We can further improve the channel capacity by employing more number of antennas in the MIMO system [5].

A good design of antenna can improve the performance of the system. In [6], authors have proposed an inverted U-shaped MIMO patch antenna which produces dual band of frequencies resonates at 2.8GHz and 6.4GHz with excellent return loss of <-25dB. Hence from the results it is concluded that this MIMO antenna is well suited for wireless(WLAN) and satellite communications.

In [7], a two element Microstrip antenna with EBG structure has been designed. Antenna play very important role in modern wireless communication system. Good design of antenna can improve performance of system. Return loss shows impedance matching and best return loss in greater than -10dB which is achieved in proposed antenna after applying EBG structure and good impedance matching also shows that available power to be absorbed and radiated by the antenna without reflections back down the line. Many factors must be considered such as operating frequencies, bandwidth requirements of the antenna system, and directivity, all of which affect its efficiency. A rectangular and circular Microstrip patch antenna has been successfully designed at the frequency of 5.85GHz. It can be concluded from the above results, while designing, a proper feed network and impedance matching are very important parameters in Microstrip patch antenna design. Further work can be done EBG structure on metamaterial. In the field of electromagnetic wave engineering the recent interest is on metamaterial technology, and application of EBG (Electromagnetic Band Gap) structure utilizing this technology to noise suppression and interference control is under consideration.

[8] Aimed at the design of a wideband microstrip patch antenna for LTE-A using etched slots at the antenna patch for bandwidth enhancement to overcome the problem occurred in classical microstrip patch antenna that suffers from very narrow bandwidth. The designed antenna has been fabricated by using thin film and photolithographic techniques and measured using the Vector Network Analyzer, The simulated and measured results were found to have good match with each other. Then using the designed single element antenna, a four-element MIMO antenna system has been built by employing orthogonal polarization diversity. Isolation between the microstrip elements is increased by placing metal structure between antenna elements. For more isolation between antenna elements, Slotted Ground Plane SGP is utilized. It is found, by using commercial software CST Microwave Studio and measurement that the designed planar MIMO antenna system has sufficiently high return loss and mutual coupling at the required bandwidth of 70 MHz. It is found also that the developed antenna system meets the requirements for LTE-Advanced (2500 – 2570 MHz) band "CA-B7" as of today"s standard based on 36.101 Table 5.5-1 (March 2012) [1]. The good return loss < -10dB, Mutual Coupling < -20 dB and required bandwidth >70 MHz are achieved. The antenna has been matched nearly to 50Ω impedance in the frequency range covering LTE-Advanced band. This work can be extended to build larger arrays.

In [9] authors have analyzed the enhancement of return loss characteristics, bandwidth and directivity gain. Proposed design gives an improved return loss of -39.99 dB at 7.7 GHz, that is embedding of meta-material give an electromagnetic resonance state at 7.7GHz, proposed antenna shows an improved directive gain of 4.35dB, since the antenna shows a lower return loss with good gain, radiation energy coupling into free space is improved and it enhances the radiation energy emitted into free space. Their by enhance the efficiency of the antenna.

The design of back to back E-shaped corner truncated microstrip patch antenna can be widely used in MIMO applications. A single modified back to back E-shaped microstrip antenna design technique using coaxial feed was presented in [10]. A 2x2 MIMO design technique yielding circular polarization and improved return loss and bandwidth was presented. The 1x1 and 2x2 MIMO system microstrip patch antenna is designed and the results are justified by simulating using IE3D simulator. The optimized antenna parameter results show that the 1x1 MIMO system antenna yields circular polarization having an axial ratio of 2.5 dBi, VSWR 1.3, 1.24 at 7.5 GHz, 8.66 GHz respectively. Return loss of about -17 dB at 7.5 GHz and -20 dB at 8.66 GHz was observed. The 2x2 MIMO antenna design yields circular polarization having an axial ratio of 1.4 dBi. An improved return loss as compared to that of the 1x1 back to back E-shape microstrip antenna of about -50 dB was obtained. The antenna has a bandwidth of 2.097 GHz. Antenna efficiency for the 2x2 MIMO system was observed to be 55% at 5.4 GHz while the radiation efficiency was observed to be 80% at 5.4 GHz.

A dual-band microstrip patch antenna array for LTE, WiMAX and other wireless applications is presented in [11]. The antenna covers 3.1 GHz and 4.5GHz frequency bands .Good results are obtained in terms of return loss, VSWR and array gain. The use of Agilent ADS software ensures that there would not be large differences between the results of simulated and measurements of fabricated antenna. The fabrication will be performed using the same FR4 substrate to compare antenna results.

A 2x2 Inset Edge Fed Elliptical shaped Micro strip Patch Antenna has been proposed. The proposed antenna resonates at 5GHz. It has been observed that for parallel structure mutual coupling is reduced; return loss and bandwidth are increased and vice-versa for orthogonal structure. The proposed study can be extended by employing antenna arrays in MIMO system for improving the channel capacity of the MIMO systems [12].

A novel compact triple band slot microstrip antenna for is presented the proposed antenna has a compact size of 60mmx40mm and it can effectively cover the 4G, WLAN Wi-MAX and Ultra Wide Band applications. In [13], design of for small-size wide-bandwidth patch antennas has been presented. These designs combine the wideband U-slot and different substrate material and the addition of a shorting pin. Simulations were presented, and three of the simulated designs were verified by EM simulator. It was found that the dielectric constant of the material decreases bandwidth will increase. Good antenna performance and impedance matching can be realized by adjusting the probe position and the dimensions of the patch.

A rectangular monopole patch antenna with a slot embedded in it has been proposed here after designing the basic geometry which is having narrow bandwidth. The impedance bandwidth of the proposed design is above 100% in all the cases studied with good radiation characteristics. Also, the proposed design requires a very less number of parameters to optimize the geometry in comparison with the meander line antennas. The proposed antenna needs to be fabricated and tested for its practical validation and should be modeled to investigate its performance in terms impedance bandwidth, gain, and radiation efficiency. The antenna presented here proves to be electrically small and is the best candidate for MIMO applications [14].

[15] Presents the analysis and designing of E-shaped patch antenna intended to be used for MIMO application at 2.4 GHz operating frequency. The simulation of the proposed design was done through Ansoft's HFSS simulation software. The fabricated antenna was tested with Agilent's network analyzer E5062A.The simulated and measured results were compared and were found to be good agreement with each other.

Comparison of Methodologies and tools used for design, simulation of antennas:

Author and Year	Achievement/ Results	Methodologies, Material and Software (s) used
Mousami Soni, Prof. Mahesh Goud 2017	Resonating Freq: 5.2 GHz Return Loss: -21 dB Gain: 4dBi Isolation: -10 dB	Patch antenna, 2X1 patch antenna slotted ground, 2X1 patch antenna full ground Material: dielectric material or Meta material
K.Kavitha, Shanmuga Priya Rajan 2017	Bandwidth: 2.3719 – 2.5839 GHz. VSWR: less than 2. Return Loss: below -10 dB Application: WLAN application	Single Band MIMO Antenna Material: Dielectric constant of 4.4. FR-4 S/W: ANSYS HFSS
Nagaraj Hanchinamani, Dr. C.R. Byrareddy 2016	Reduced mutual coupling: less than -10dB. Resonating Freq: 9.256GHz VSWR: ≤2. Bandwidth: 7.14-7.42GHz, 7.6-8.2GHz, 8.2-8.6GHz, 9.8-10.2GHz Application: Wi-Fi, WiMAX, and 3G/4G.	2x1 MIMO implementation for wireless applications, Defective Ground structure(DGS) Material: FR4 substrate with thickness (hs) of 1.6mm having relative permittivity (Ɛr) of 4.4. S/W: CST Microwave studio suit 2015
Hassan M. Elkamchouchi, Rateba A. Salem. 2016	Resonating Freq: 8GHz. Return Loss: -26.4881 VSWR: ≤ 1dB (0.2551) Bandwidth: 7.2GHz to 12GHz. Application: Radar, Satellite communication, biomedical application, Remote sensing etc.	I slot microstrip patch antenna Material: Rogers RT/duriod substrate with dielectric constant 2.2 with microsrip line feed S/W: High Frequency Structure Simulator Software (HFSS).
Y.V.S.S. Satya Mitra et. al. 2016	Resonating Freq: 5.4 GHz Isolation: -31 dB Application: 5G and beyond	2×2 MIMO System Material: Rogers RT Duroid 5880
T.Mohan Krishna 2015	VSWR: less than 2 Resonating Freq: 2.8GHz and6.4GHz, Return Loss: -25 dB and -27 dB respectively Application: WLAN and satellite applications	U-Shaped MIMO Patch Antenna Material: dielectric FR-4 substrate
Abhishek Sharma et.al. 2015	Resonating Freq: 5.85GHz Return Loss: -7.8 dB to -19dB Efficiency: 90-91% Gain: 6.5- 6.6 Application: Radio frequency identifications (RFID)	2 element MIMO patch antenna array with EBG structure Material: FR4 substrate S/W: Zeland IE3D Software
A.A. Asaker et. al. 2015	Reduced mutual coupling: -20 dB Resonating Freq: 2.53 GHz Reflection coeff.: -10 VSWR: ≤ 2 Return Loss: -10dB	Two Element MIMO Array with Polarization Diversity, Four Element MIMO Array with Polarization Diversity Material: FR-4 S/W: Zeland IE3D Software

<table>
<tr><td></td><td>Impedance: matched nearly to 50Ω impedance Bandwidth: 2.48 GHz up to 2.58 GHz.
Application: WLAN</td><td></td></tr>
<tr><td>Arun Balan et.al. 2015</td><td>Resonating Freq: 7.7GHz
Return Loss: -39.99dB
Gain: 2.53dB.
Bandwidth: 35%</td><td>Meta-material embedded symmetric multi-slot antenna
Material:
Meta-material</td></tr>
<tr><td>Prajakta Doiphode, Sharad Wagh 2014</td><td>Bandwidth: 2.097 GHz.
VSWR: 1.3
Resonating Freq: 2.097 GHz
Return Loss:-17 dB
Gain: 5.15 dBi at 5.4 GHz
Directivity = 8 dBi at 5.4 GHz
Directivity = 10 dBi at 7.5 GHz
Antenna efficiency: 55% at 5.4 GHz
Radiation efficiency: 80% at 5.4 GHz.
Application: Wi-MAX, WLAN.</td><td>E-shaped rectangular microstrip patch antenna
Material:
RT/duroid (5880) substrate, having dielectric constant εr = 2.2
S/W:
IE3D simulator from Zeland</td></tr>
<tr><td>R.Rajeswari et. al. 2014</td><td>Reduced mutual coupling:
Resonating Freq: 3.5 GHz and 5GHz
VSWR: 1.11-1.36
Bandwidth: 50MHz-150Mhz
Data rate: 1Gbps
Efficiency: 73.05%.
Gain: 5.006- 9.95
Return Loss: -16.18dB to -25.28dB
Application: LTE (Long Term Evolution), WiMAX</td><td>Dissimilar patch size array antenna, Four element antenna design, Eight element antenna design,
Material:
FR4 (∈ =4.6)
S/W:
Agilent ADS Momentum</td></tr>
<tr><td>Rajesh Hooda 2014</td><td>Resonating Freq: 5GHz
Return Loss: -26.5dB
Bandwidth: 150.8MHz
Isolation: 22.5dB
Application: Wi-Fi, 3G and 4G etc.</td><td>2x2 MIMO elliptical shaped micro strip patch antenna,
Material:
Not Mentioned
S/W: HFSS</td></tr>
<tr><td>P. Kiran et. al. 2013</td><td>Reduced mutual coupling:-23dB
Resonating Freq: 3.7GHz,5.8GHz and 7.1GHz
VSWR: ≤ 2.5
Impedance bandwidth: 42%
Bandwidth: 54%
Isolation: 28dB
Application: 4G, WLAN,Wi-MAX</td><td>Two Element MIMO System, U-Slot Patch Antenna with a Shorting Pin
Material:
<table>
<tr><th>S.NO</th><th>Material</th><th>Dielectric constant</th><th>Impedance Band Width</th></tr>
<tr><td>1)</td><td>Air</td><td>1</td><td>42%</td></tr>
<tr><td>2)</td><td>Rogers RT/Duroid 5880</td><td>2.2</td><td>35%</td></tr>
<tr><td>3)</td><td>Epoxy</td><td>3.6</td><td>24%</td></tr>
<tr><td>4)</td><td>FR4 epoxy</td><td>4.4</td><td>10%</td></tr>
</table>
S/W:
EM simulator</td></tr>
<tr><td>Mahesh C. Bhad et. al. 2012</td><td>Resonating Freq: 1.7GHz
Impedance bandwidth: 105%
Bandwidth: 0.8GHz to 2.6GHz
Application: MIMO applications</td><td>Effect of Patch Length,Effect of Slot Dimensions,
Material: FR4
S/W: Ansoft HFSS software</td></tr>
</table>

M.B.Kadu et.al 2012	Resonating Freq: 2.4GHz ISM Band Return Loss: -24.06dB VSWR: ≤ 1.05 Application: WLAN	E-SHAPED PATCH ANTENNAS Material: FR-4 S/W: Ansoft's HFSS 11.1v.

Table 1: Summary of literature survey

III. Conclusion

Table 1 summaries the various articles using different design methodologies, simulation tools, materials used and results obtained. This summary helps researchers who want to showcase their creativity and use technical skill to develop high performance antennas. From this we conclude that it is possible to design and fabricate an antenna with for wide range of frequency with return loss below -10 dB, Gain up to 6dBi, VSWR less than 2, Efficiency more than 75% for wide range of applications.

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