MIMO Antennas - A review

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Received: February 05, 2019 Accepted: March 23, 2019

ABSTRACT: *The paper serves as a tutorial on the study and evaluation of antennas for multiple input multiple output communication systems.MIMO provides additional degrees of freedom by providing a number of antennas at both transmitter and receiver .The antennas along with smart signal processing provide spatial multiplexing or diversity combining,thus exploiting multipath propagation.The performance of MIMO is greatly dictated by the correlation among the multipath components.Low correlation ensures enhanced performance with increased capacity. The objective of the work is to review the recent research and development trends and highlight few novel approaches in the antenna design that calls for MIMO applications.*

Key Words: *Printed antennas, multiple-input-multiple-output (MIMO), Decoupling techniques, Isolation, correlation coefficient.*

I. Introduction

The evolution of MIMO dates back to 1993,when it was thought as a method of broadcasting by splitting a high-rate signal into several low-rate signals transmitted from spatially separated transmitters and recovered by the receive antenna array based on differences in directions-of-arrival. Multiple-input-multiple-output (MIMO) technology is used ubiquitously in modern communications,employing multiple antenna elements to improve bandwidth efficiency and capacity. It is a promising solution to cater to the increasing demands for a higher data rate in wireless communication systems,exploiting multipath propagation.Thus MIMO achieves spatial diversity and spatial multiplexing.

A novel approach in wireless communication industry drive the requirements for compact,simple,compatible and affordable antennas with ease of integration. The performance of a MIMO system greatly depends on the correlation behaviour of its multipath signal,characterized by the channel matrix. The channel rank, a measure of the number of uncorrelated channel path gains determines capacity[1].Low correlation is achieved by exploiting the various techniques of antenna placement and incorporating special decoupling structures.

This paper is organized as follows; Section 2 gives an overview of the decoupling techniques that are predominantly used in MIMO antenna design and their influences on performance.Section 3 reviews the innovative antenna designs employing these decoupling techniques.This section throws light on issues related to size, cost, implementation complexity and its impact on performance. Section 4 discusses on the capacity considerations and Section 5 concludes this paper.

II. REVIEW OF DECOUPLING TECHNIQUES

Wireless networks are spread everywhere and compact comfortable mobile devices doesnot restrict mobility of people.The great challenge to MIMO antenna industry is to fit the multiple antenna elements within the compact space of portable equipments,wherein mutual coupling arises due to electromagnetic interference of radiation from adjacent antennas causing information loss as well as performance degradation.Mutual coupling alters the matching criteria of antenna elements and thus changes the received element power and radiation pattern. It is detrimental to antenna performance and has attracted a large volume of research to study its causes and remedies.The emergence of ultra compact radio transceivers has favoured the development of small-size antenna in recent years thus placing the study of mutual coupling in top most priority.

Isolation can be achieved using special decoupling structures[1],that provides an extra path for coupling fields to induce new current in opposite phase between the elements,thus compensating the electric and magnetic coupling between two ports.Decoupling can also be realised using transmission line[2] where the antenna elements are connected by an admittance transformer which connects to the ports in parallel electrically.Decoupling is achieved by varying the length and the width of the admittance transformer to retrieve the mutual admittance having only imaginary part that gets cancelled out due to parallel connection. Pattern diversity [3] presents isolation enhancement by employing antenna elements on either side of a rectangular ground plane,whereby varied modes of radiation are excited. Isolation can also be obtained by incorporating feeds in dual polarisation[16] whereby the formation of orthogonal surface currents provides polarisation diversity. Slots[16] and Neutralisation lines[4,5,8] also aid decoupling in designs where there occurs a strong coupling due to induced currents because of near field coupling and common ground.Neutralisation lines introduce new current paths between the elements producing new couplings to compensate for the original coupling thereby providing isolation enhancement . Electromagnetic band gap structures[12] realises a parallel LC resonant circuit by virtue of meander design, exhibiting forbidden frequency bands thereby prohibiting surface wave propagation and helps reduce mutual coupling. Modification of the ground[6] help mitigate coupling.The defect in the ground cancels the fields around the defect realising band stop characteristics suppressing higher order harmonics.Mutual coupling is also mitigated by metamaterials realized using SRR[7] which possess negative permittivity and negative permeability by phase compensation technique. Decoupling can be achieved by using ground stubs and slots on the radiator[16]. The stub helps leaked energy to short to the ground,its function similar to that of a band-stop filter having series inductance and shunt capacitance. Slots on the radiator contain the RF current on the edges of the structure thereby reduce mutual coupling.

III. MIMO Antennas-a survey

A detailed survey conducted on MIMO antennas with a suitable decoupling technique for varied applications is presented here.

There is a minkowski method discussed by K. Vasu Babu and B. Anuradha[9],where rectangular slots of various size and shape are cut off in each side of the patch.The antenna exhibits multiband resonant frequencies in 2-8GHz band on a dimension of 60x40mm^2.Low mutual coupling as observed from S_{12}=-54db is due to surface current distribution due to various discontinuities in the patch edges. The antenna gain varies from 3.4 - 7.9 dBi and directivity 6dbi. The radiation patterns in H-plane are almost omni-directional while the radiation patterns in E-plane are nearly bidirectional.The antenna shows low correlation with ECC value of 0.045.The antenna is applicable in WLAN and Wimax bands.

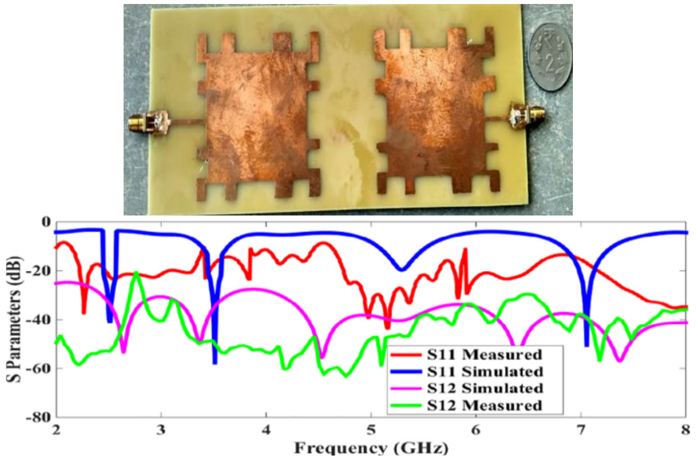


Fig 1.Minkowaski antenna and its performance

A method of using slot and strip to achieve decoupling is elaborately discussed by Pratima C. Nirmal.et.al [10].The proposed design consists of two F shaped monopoles counter facing each other in a compact space of 30 × 26mm^2 resonates for dualbands at 3.2–3.8GHz and 5.7–6.2GHz to cover Wimax and WLAN applications.The antenna shows good isolation performance with S_{12} < −20 dB for the included bands with gain 3dbi. The surface current is contained around the elliptical slot in lower band whereas rectangular parasitic strips takes care of the current in the upper band.

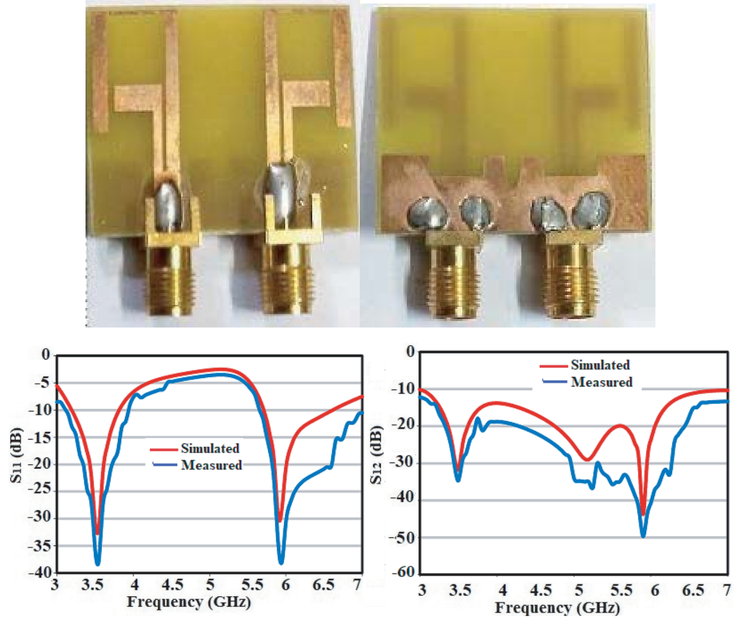


Fig. 2.F-antenna with parasitic strips and its performance

In a work done by Anveshkumar Nella and A.S.Gandhi [11],a compact five-port integrated ultra wideband (UWB) and narrowband(NB) antenna system for cognitive radio application is proposed. The antenna system comprises of one UWB antenna for spectrum sensing and four NB antennas for communication. The antennas are printed on a very compact dimension 40×36mm^2 with gain ranging from 1.5-5.5dbi. The partial ground plane shows good isolation performance with $S_{12} < -20$ dB.Omnidirectional radiation patterns are exhibited by UWB, third and fourth NB antennas whereas the first and second NB antennas exhibit slight directional patterns owing to full ground plane.

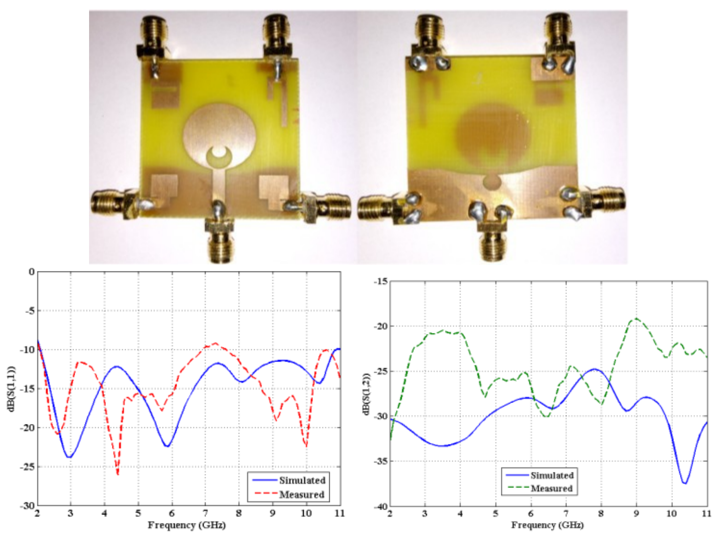


Fig. 3.UWB and Narrowband antenna and its performance

In the literature presented by Niraj Kumar and Usha K. Kommuri[12],a novel *E and H* plane spiro meander line uniplanar compact electromagnetic bandgap (E/H-SMLUC-EBG)structures are used to help alleviate mutual coupling by placing an EBG structure between the radiating elements,whereby the surface currents get coupled through the structures.They provide an equivalent transmission line with inductance and capacitance.The antenna is compact with dimensions 48x16 mm^2 resonates for 5.8GHz WLAN band with isolation performance shown from S_{12}=-40db.The antenna gives a correlation factor of 0.4.The radiation pattern is not affected by the inclusion of EBG structures.

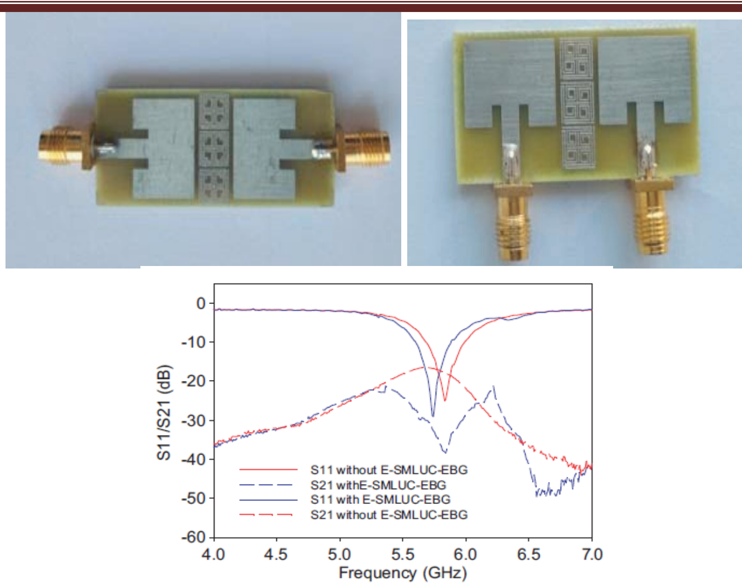


Fig. 4.EBG based patch antenna and its performance.

In a work proposed by H. Li.et.al[13],textile MIMO antenna is designed for wearable applications.The antenna employs a small ground plane as the main radiator, loaded capacitively by two strips along two orthogonal edges.The antenna employs pattern and polarization diversities and provides isolation as observed from S12<-15db due to the quasi-orthogonal radiations generated by the two antenna elements.The antenna is resonant at 2.4GHz and works on a compact dimension of 38.1x38.1mm^2 with on body gain of 1.2dbi.The pattern is similar to x and y oriented dipoles with ECC 0.01.

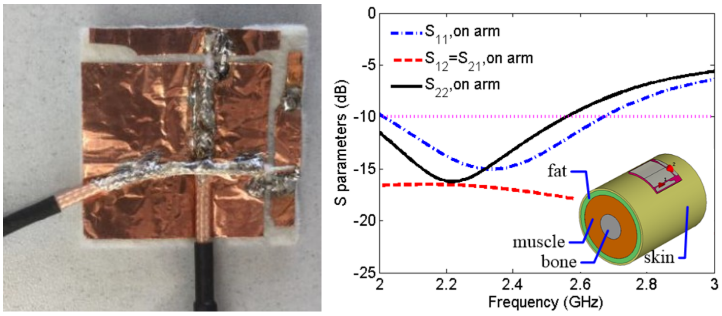
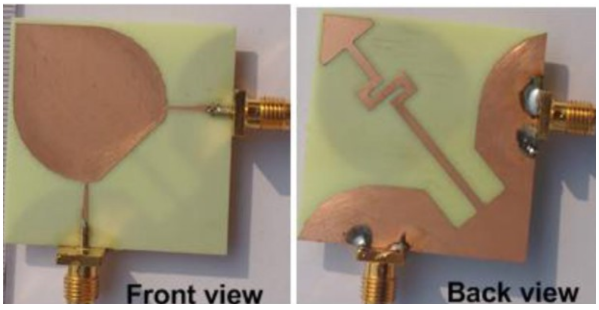


Fig. 5. Wearable textile antenna and its performance

In the work by Situ Rani Patre and Surya P. Singh[14],compact shared radiator MIMO antenna is discussed.The leaf shaped radiator is fed by two orthogonal tapered microstrip lines at dual polarisation.Isolation is achieved by using end-loaded meandered stub line connected to modified curved ground plane. A small portion of the basic circular radiator is removed which helps in directing higher level of surface current towards the upper boundary of radiator, where a meandered ground branch is extended thereby reducing the coupling.the antenna is resonant from 2.5-12.5GHz covering ultra wide band with a peak gain of 5.22 dbi.Moreover it exhibits good isolation as evident from S12<-12db with ECC <0.02.Radiation pattern shows wide variation over the band.



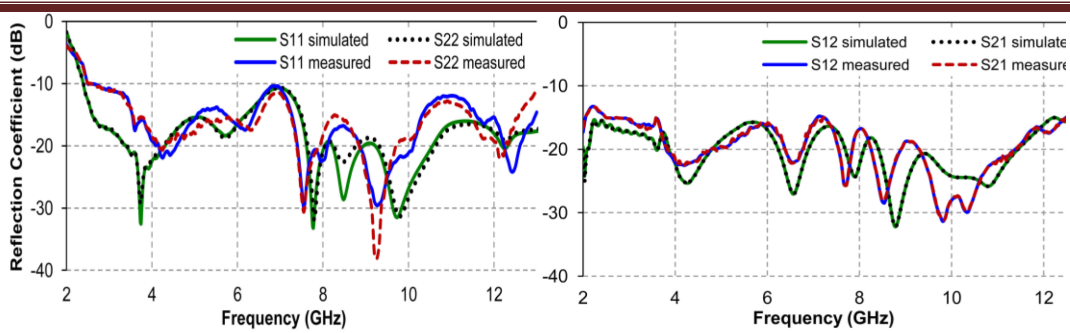


Fig. 6.Shared radiator antenna and its performance

The literature by Mohammad S. Sharawi.et.al[15] discusses the design of first ever 4G/5G MIMO antenna system,which has a 2 element slot based system for 4G and 1x2 Connected Antenna array based system for 5G.It is a multiband antenna system with a gain of 2.2 dbi in 4G and 8dbi in 5G.The system had used Rogers substrate with a dimensions 100x60mm^2.Slots are made on the ground plane in connected antenna array(CAA) style working as a band reject filter that help enhance isolation as given by S12=<-10db.The antenna is resonant for 2-3.5GHz for 4G and 16.50-17.80 GHz for 5G applications.The antenna shows dipole like pattern for 4G bands and near directional pattern for 5G.The ECC value works to 0.05 at high frequency and 0.3 at low frequencies.

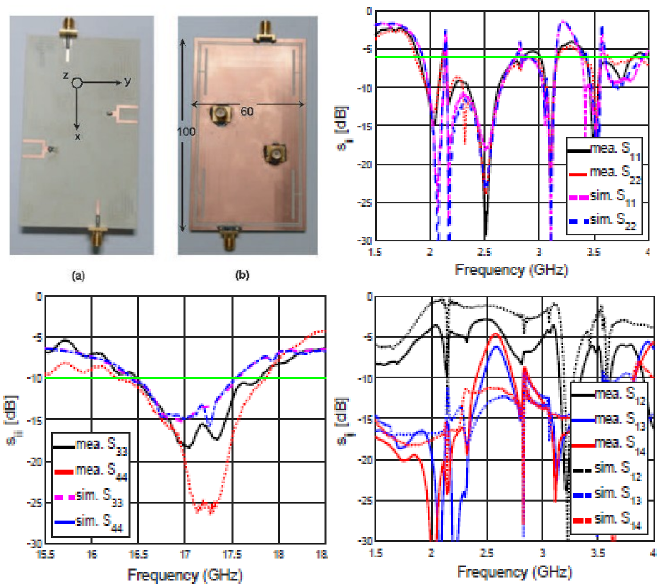
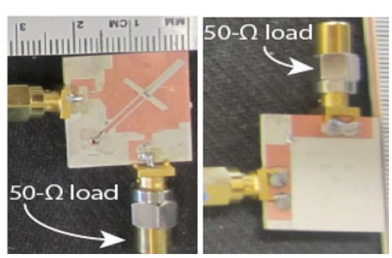


Fig. 7.Connected Antenna array based slot antenna and its performance

The literature by Muhammad Saeed Khan[16]discusses ultra compact antenna system of size 22×24.3mm^2 using shared radiator with meandered feed to achieve compactness.The use of slots in the radiator,open shunt stub in the centre,partial ground plane helps combat mutual coupling.The system is built over Rogers substrate covering UWB band with a gain of 1.8 to 5.2dbi with isolation given by S_{12}< -15db and ECC<0.42.Being the much compact system in the existing literature,it is suitable for mobile and handheld applications.



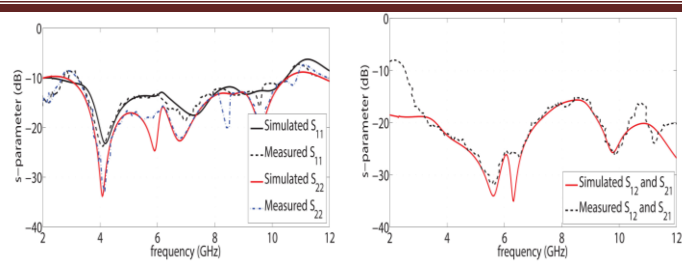


Fig. 8.Ultra compact shared radiator antenna and its performance

Multiband antenna for 4G and 5G applications [17]presents a comfortable antenna system for smartphones of size 75×150 mm^2 using double-element square-ring slot radiators with microstripline feed for easy integration.The use of slots in the radiator,helps combat mutual coupling.The system is built over lossless FR4 substrate covering various LTE bands with a gain of 2.5 to 5.2dbi with isolation given by S_{12}< -17db and ECC<0.5.Being an efficient 4x4 system in the existing literature,it is suitable for mobile and handheld applications.

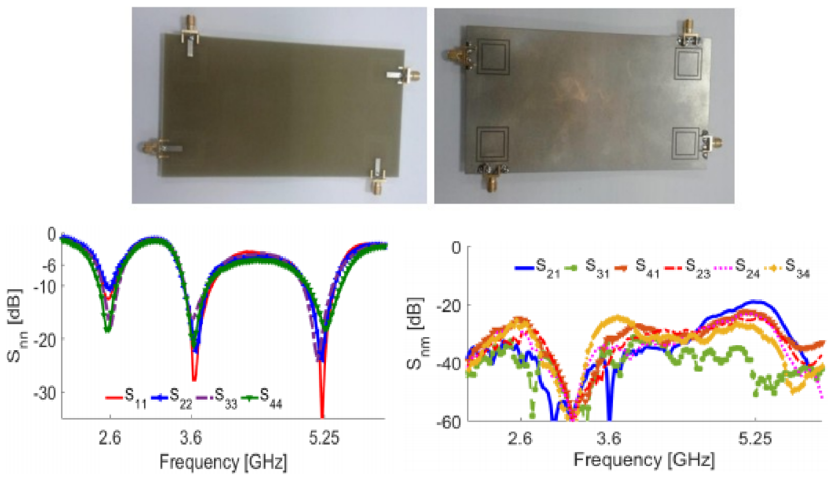


Fig. 9.Square ringed antenna and its performance.

IV. CAPACITY CONSIDERATIONS

A wireless system exhibits more flexibility than a wired system,with MIMO providing channel enhancement, promising high data transfer rate at power and bandwidth constraints.MIMO capacity heavily depends on the statistical properties of scattering environment like fading,doppler spread,etc and antenna correlation based on the type,configuration and placement of antenna elements. MIMO transmission can be thought as a set of recordings on every receiver antenna with the number of transmitted signals. If every equation represents a unique mapping, then there exists a unique solution to the problem.With M antennas at th e transmitter and N antennas at the receiver,the optimum capacity is given by

$C_{opt} = \min(M,N)[\log_2(1 + SNR(\max(M,N))]$

Thus it is evident that we have an impressive linear capacity growth with the increase in number of antenna elements.

TABLE 1. COMPARISON OF ANTENNA DESIGN FOR VARIED APPLICATIONS

Author (Year)	Type of antenna	Decoupling Technique	Design Parameters	Application
Vasu Babu (2018) [9]	Minkowski patch antenna	Antenna structure and differential arrangement S_{12}:44-54 db ECC:0.02-0.0039	Res Freq: 2.1-2.6, 3.2–3.7, 4.8–5.4, 6.6–7.4GHz BW: 0.5-1GHz(Multiband) Dimension:60x40mm^2 Gain:3.4-7.9dbi	Varied wireless applications
Pratima C. Nirmal (2018) [10]	Counterfacing F shaped monopole Antenna	Elliptical slot and parasitic strip S_{12}:<20 db ECC:0.03	Res Freq: 3.2–3.8,5.7–6.2GHz BW: 0.5GHz Dimension:30x26mm^2 Gain:1.5 and 2.8dbi	Wi-max,WLAN
Anveshkumar Nella (2018)	UWB and 4 Narrow	Partial ground S_{12}:<20 db	Res Freq: UWB and switched bands in UWB for	Cognitive radio Spectrum sensing

[11]	band(NB) antennas		NB antennas BW: UWB Dimension:40x36mm^2 Gain:1.5-5.5dbi	
Niraj kumar(2018) [12]	E&H Spiro meander line EBG antenna	EBG decoupling S_{12}:40 db ECC:0.4	Res Freq:5.8GHz BW:400MHz Dimension: 48x16mm^2	WLAN
H.Li (2018) [13]	Textile antenna with dual feed	Capacitively loaded orthogonal strips S_{12}:<15 db ECC:0.01	Res Freq:2.4GHz BW:0.5GHz Dimension: 38.1x38.1 mm^2 Gain:1.2dbi	Wearable applications
Situ Rani Patre (2018) [14]	Leaf like shared radiator with meandered dual feed	Modified ground Polarisation diversity S_{12}:<15 db ECC:0.2	Res Freq: 2.5-12.5 GHz BW: UWB Dimension:39x39 mm^2 Gain:5.2.2dbi	UWB applications
S. Sharawi (2017) [15]	Integrated 4G/5G antenna	Slots in ground in connected antenna array fashion S_{12}:<10 db ECC:0.3 & 0.05	Res Freq: 2-3.5 GHz(4G) 16.50-17.80 GHz (5G) BW: 1.5GHz Dimension:100x60 mm^2 Gain:2.2 and 8 dbi	4G/5G applications
Khan (2017) [16]	Modified-patch shared radiator antenna with dual polarized meandered feed.	Slots in radiator,open shunt stub,partial ground S_{12}:<15 db ECC:0.42	Res Freq: 2-11 GHz BW: UWB Dimension:22x24.3mm^2 Gain:1.8-5.2dbi	UWB applications
Peng Liu (2018) [1]	Counter facing F shaped antenna	Decoupling network S_{12}:35 db ECC:0.01	Res Freq:2-46-2.7 GHz 5.04-5.5 GHz Dimension:74x47.3mm^2 Gain:3 dbi	WLAN
Nguyen Khac Kiem (2018) [2]	Symmetrical rod like monopole	Transmission line decoupling S_{12}:<20db ECC:0.5	Res Freq:2.45,5.25 and 1.8,3.5GHz BW: 1 GHz Dimension: 55x22.83 mm^2 Gain:4.5 and 5.3 dbi	WLAN,LTE,Wimax
Xing Zhao (2017) [3]	Quarter loop and circular monopole	Pattern diversity S_{12}:40db ECC:0.03	Res freq:2-9.5GHz BW:7.5GHz Dimension: 110x60 mm^2 Gain:1.5dbi	Mobile applications
Xinyao Luo (2017) [4]	Miniaturised PIFA	Slot decoupling S_{12}:50db ECC:0.03	Res Freq: 2.4 and 5 GHz (Dual) BW: 2.4 and 5 GHz Dimension: 31x17mm^2 Gain:2.66 and 5.18dbi	WLAN
Yangsong Ou (2017) [5]	Open loop like antenna over partial ground	Neutralisation line decoupling S_{12}:30db ECC:0.006	Res Freq:2.45 and 5.8GHz BW: 500MHz Dimension: 50x40 mm^2	WLAN
Guohua Zhai (2015) [7]	Substrate Integrated cavity-backed slot antenna	Metamaterial decoupling S_{12}:42db ECC:0.02	Res Freq:2.4GHz BW: 2.396-2.42GHz Dimension: 113x50.2 mm^2 Gain:5.1dbi	ISM applications
Yan Wang (2014) [8]	S shaped monopole antenna	Neutralisation line decoupling S_{12}:40db ECC:0.009	Res Freq:1.62-2.92 GHz BW:1.3GHz Dimension: 100x60mm^2 Gain:5 dbi	GSM1800, GSM1900, UMTS, LTE2300, LTE2500, and 2.4-GHz WLAN
Tanvi	Meander	Defected ground	Res Freq:	Wi-Fi,Wimax,LTE

Agarwal (2017) [6]	radiator	decoupling S_{12}:<30db ECC:0.05	1.8,2.4,3.4,4.18,5.2,5.5 6.1 GHz(Multiband) BW: 0.3GHz Dimension:102x80 mm^2 Gain:8.3dbi	

V. CONCLUSION

This communication presents a brief review on recent research findings concerning antenna design for MIMO systems.It is understood that the antenna configuration,topology and decorrelation between the antennas help enhance performance of a practical MIMO system.Hence a comparitive study on mutual coupling mitigation is also done. It is not feasible to carry out an efficient comparison among the antennas since they vary widely in operating frequency,bandwidth,area,material used,etc.A pragmatic model is found to increase the capacity of practical MIMO system depending on the SNR of the transmitted signal and number of antenna elements in antenna array. There is a need to optimise the antenna parameters and design procedure for enhanced operation. It is concluded that MIMO had shown lot of scope for research and development in the arena for antenna design as we are gradually moving towards 5G.

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