

A Review on MIMO Antenna Developments: Basics Parameters, Design Techniques and Its Applications

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Abstract: The review article provides state of the art development and innovation of Multiple-input multiple-output (MIMO) antennas over the last few years. The objective of the review article is to highlight the basic concept of MIMO antenna with their essential parameters and state-of-the-art development of MIMO antennas in terms of ultra wideband with isolation techniques. The design techniques and methods to enhance MIMO antenna bandwidth and isolation are presented. In addition to the techniques, real field potential applications of the design MIMO antenna is a major objective of the article and that play an important role in modern digital wireless communications. In order to fulfill these objectives, real fields of potential applications are also presented.

Keywords: Isolation Enhancement Techniques; MIMO Antenna; Potential Applications; Wireless Communication; UWB

Introduction

In the present scenario, wireless systems with high data rates and adequate channel capacity are essential for advanced modern wireless communication systems. To meet the above requirements, MIMO antenna is an emerging solution for this modern technology. It offers several advantages such as increased data throughput, improved spectral efficiency, enhanced signal quality, better coverage and range, higher network capacity, increased energy efficiency and robustness against interference [1-3]. MIMO antenna consists of two or more radiating elements i.e. patch or dielectric resonator (DR) are fed by different feeding mechanisms such as microstrip feed, coplanar waveguide feed and coaxial probe feed to transmit and receive the data simultaneously. Although, the mutual coupling between the two antennas ports is a major challenge in MIMO structure because it disrupts the optimal performance of MIMO antennas [4-5]. As a design approaches with specific techniques in order to achieve the optimal antenna performance. Besides, the comparison tables presented in the article will help antenna researchers or designers to implement and modify the described techniques for optimal performance of MIMO antennas. The utilization of MIMO antenna based on implementation of different techniques and modification of radiating patch and ground plane with stubs geometry are quite important from the research point of view, but cognitively it is incomplete without a real field of potential applications. By considering the above highlights points, the authors have presented the potential applications in terms of different categories from the instances available in the open literature. It gives a brief idea about the progress of research done from applications point of view. Consequently, numerous strategies have been employed to enhance the isolation between the antenna radiators. Initially, researchers have investigated the MIMO parameters theoretically [6-7]. Later, the concept of MIMO was implemented in the antenna to transmit and receive the data. Apart from this, a high-gain antenna is one of the major concerns of MIMO antenna performance for applications of long-distance communication. To achieve high gain, the antenna must have a well-designed radiation pattern with a narrow beam-width, minimizing interference and maximizing signal focus.

In this review article, MIMO antenna designs for ultra wideband and their techniques with performances are reported. This review article mainly focuses on well-organized information about MIMO antennas. This review article is organized in five sections, starting with the introduction; in Section 2, the basics of MIMO antenna and their parameters are presented; in Section 3, review of MIMO antenna development with their techniques and parameters over the few years are presented. MIMO antenna in-terms of real-field applications in Section 4. Finally, the rework is concluded in Section 5.

Basic of MIMO Antenna and their Diversity Parameters

MIMO antenna technology has received a key attention in modern wireless communication systems, significantly improving data rates, capacity, and reliability and hence increasing the range and output performance [8]. It uses multiple antennas at both the transmitter and receiver to take advantage of spatial diversity and multipath propagation. However, the significant isolation

between antenna ports of the same MIMO system is necessary so that elements of the MIMO antenna can work independently to transmit or receive signals simultaneously without deteriorating the antenna parameters. Apart from diversity parameters, antenna parameters like S-parameter, gain, efficiency and radiation pattern are also important for standalone antenna analysis.

MIMO antennas have received much attention in the modern wireless communication system as it can use multi-paths to transmit or receive data, and hence increase the range and output performance. It is noted that the significant isolation between components of the same MIMO system is necessary so that elements of the MIMO antenna can work independently to transmit or receive signals simultaneously without deteriorating the antenna parameters. In order to ensure the quality of a MIMO antenna, in addition to S-parameters and radiation characteristics, certain diversity parameters are used. The MIMO antennas must satisfy the predefined values of the diversity parameters for practical applications. Therefore, some basic diversity parameters for MIMO antennas are mentioned in this section.

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Diversity Parameters

In MIMO antenna performance, the diversity parameters plays a crucial role to determine the best MIMO antenna in wireless communication systems. The MIMO antenna parameters should satisfy the predefined value or limit of the diversity parameters for real field practical applications. Thus, basic diversity parameters of the MIMO antenna are briefly discussed in this section.

Envelope Correlation Coefficient (ECC): The Envelope Correlation Coefficient is a key parameter that indicates the correlation between the adjacent MIMO antenna elements. This diversity parameter is used to evaluate the performance of MIMO antenna systems. It can be calculated from the far field radiation patterns of the antenna. It measures the level of correlation between signals received or transmitted by different antennas in a MIMO system [9].

Diversity Gain (DG): Diversity Gain is another performance metric in MIMO antenna systems that measure how efficiently a system reduces signal fading by employing multiple antennas. Also, it indicates the quality and reliability of a MIMO antenna in wireless systems.

Channel Capacity Loss (CCL): The CCL is a diversity parameter of the MIMO antenna that is defined as the maximum limit up to which the information can be transmitted with almost zero loss in the communication channel [10].

Mean Effective Gain (MEG): Mean Effective Gain is a crucial parameter of MIMO antennas that is used to evaluate the performance of MIMO antennas in a wireless communication environment. It is defined as the ratio of power received by the MIMO antenna to the power received by the isotropic antenna.

A Review on MIMO Antenna Developments

This section highlights the state-of-the-art developments of MIMO antennas over the last few years. It mainly consists of UWB MIMO antenna and Isolation techniques. To generate the UWB band in MIMO antenna, modification of different radiating patches and ground planes have been implemented and their performances are reported.

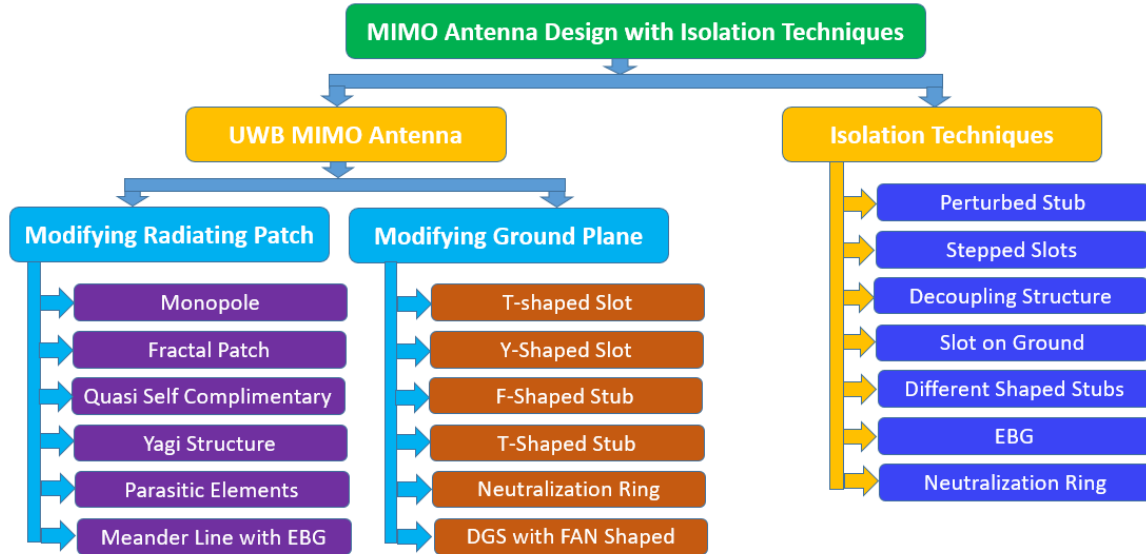


Figure 1. The outlines of the review article on MIMO Antenna

In addition, real field potential applications are presented for the corresponding MIMO antennas. The outline of the review article on MIMO antenna is presented in Figure 1. In this MIMO review paper, the authors have presented different techniques and their development, which will be helpful to the researcher to get the complete idea about the developments of particular techniques and easily find the innovation techniques for the same.

UWB MIMO Antennas with Isolation Techniques: In this section, various techniques have been implemented to achieve ultra wideband frequency range in MIMO antennas. In general, the UWB band covers 3.1GHz to 10.6 GHz frequency band. Different implemented techniques such as modifying the radiating patch, fractal patch, monopole patch with components, modifying the ground plane with stubs and slits are reported in chronological order over the last few years of research work.

Circular-shaped printed MIMO monopole antenna is presented for the generation of the UWB frequency band [11]. The measured impedance bandwidth ($S_{11} < -10\text{dB}$) is 2.82 GHz to 16.2 GHz. In addition, to improve the isolation between the antenna patches, a circular monopole with two slotted T-shaped stubs and perturbed strips is implemented as shown in Figure 2. The measured isolation is observed above 25dB in most of the band i.e. (90%) with better antenna diversity parameters.

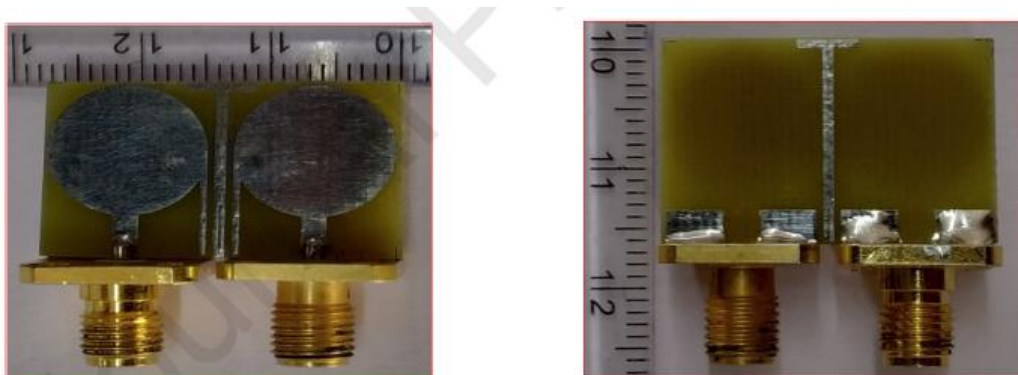


Figure 2. Circular-shaped printed UWB MIMO antenna

In order to reduce the overall size of the antenna, a compact modified sierpinski carpet fractal antenna is investigated for UWB MIMO antenna performance [12]. Here, the Iterated function system (IFS) method is implemented to design the sierpinski carpet fractal structure. Due this fractal structure, the impedance bandwidth is improved with miniaturizing the overall antenna size.

Further, square-shaped funnel-like ground stub with a vertical slot is implemented on the bottom of the substrate to enhance the isolation between the ports as shown in Figure 3. The measured impedance bandwidth and isolation are 3 GHz to 12.6 GHz and 16.3 dB respectively.

A novel technique i.e. a compact UWB half circular shaped monopole antenna monopole is presented for UWB MIMO application [13]. By arranging quasi-self-complementary half circular shaped monopoles, the isolation is improved without implementing any decoupling method as shown in Figure 4. The obtained impedance bandwidth and isolation are 2.19 GHz to 11.07 GHz and 20 dB respectively.

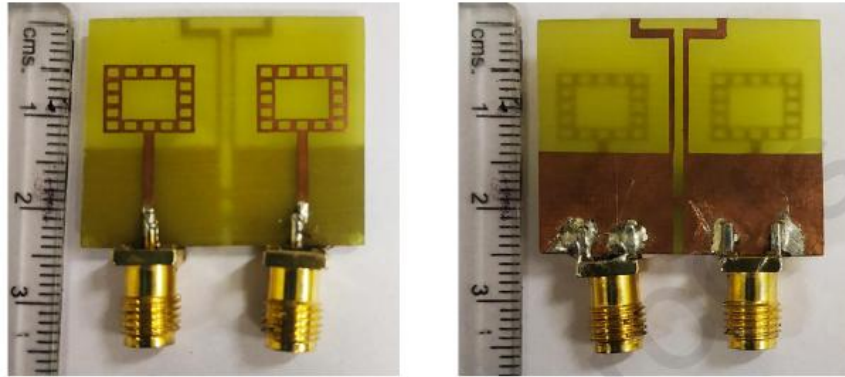


Figure 3. Sierpinski carpet fractal UWB MIMO antenna

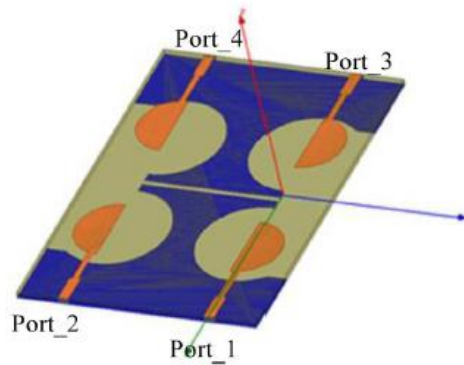


Figure 4. Compact UWB MIMO antenna using quasi-self-complementary antenna

Furthermore, a yagi based MIMO antenna is investigated for UWB applications [14]. The intuition behind the implemented work is that half of the driven loop element is implemented on each side of the substrate that not only miniaturizes the antenna but also increases the impedance bandwidth of the antenna drastically as shown in Figure 5. The proposed design bandwidth is 4.183 GHz to 6.584 GHz with reduction of overall size nearly about 45%. As the antenna is a yagi structure, it provides a high directional radiation pattern with FBR and gain of 18 dB and 6 dB respectively.

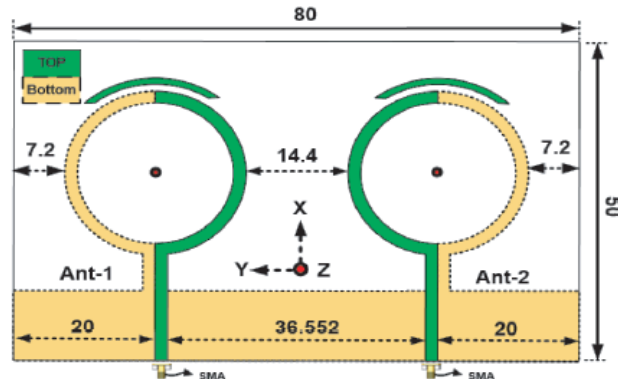


Figure 5. Yagi based UWB MIMO antenna

An active amplifier integrated UWB MIMO antenna is presented to increase the high gain i.e. 14.1 dB of the complete system [15]. In this work, the antenna and amplifier interface is not matched with 50 ohm, they are designed in such a way that it improves wideband impedance matching along with antenna efficiency as shown in Figure 6. The measured antenna bandwidth and efficiency are 1.8 GHz to 5.5 GHz and 60%.



Figure 6. Active Integrated Ultra-Wideband MIMO Antenna

A UWB band with high isolation can be achieved by implementing the slots on radiating patches along with a monopole. Some of the research work has investigated the MIMO antenna diversity parameter with wide impedance bandwidth by implementing the slots on radiating patches with desired monopole patch. A compact coplanar strip line fed staircase-shaped radiating element MIMO antenna is proposed for UWB with high isolation application [16]. The structure is arranged back to back with an isolating metal strip between two radiating elements to improve the isolation i.e. better than 20 dB with impedance bandwidth of 3.1 GHz to 10.6 GHz as shown in Figure 7.

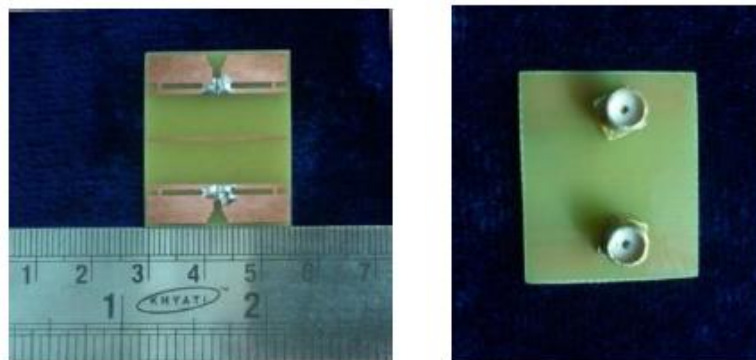


Figure 7. Compact UWB MIMO Antenna with Reflector to Enhance Isolation

Similarly, other research work related to implementing the slots on radiating patches along with a monopole is presented. Starting from stepped monopole with microstrip feed stepped slot [17], annular ring monopole with slotted annular ring [18], modified triangular monopole with components such as varactor diode & PIN for reconfigurable [9], fence type decoupling structure with L-shaped parasitic branches [20], semicircular slot loaded monopole with staircase ground plane [21], monopole antenna with taper impedance adapter [22], hexagonal ring monopole with slots on ground plane [23], rectangular monopole with mender line electromagnetic band gap (EBG) on both top and bottom layer of substrate [24], frog shape with T-shaped floor [25], rectangular monopole with A shaped slots in radiating patch [26], and Racket-shaped monopole with cross slots on the original T-shaped floor [27] have deeply investigated their performance in terms of bandwidth, isolation and diversity parameter of MIMO antennas. These novel techniques have been implemented to improve the impedance bandwidth and isolation between the antenna elements. The detailed antenna parameters are tabulated in Table-1. The corresponding prototype is presented in Figure 8.

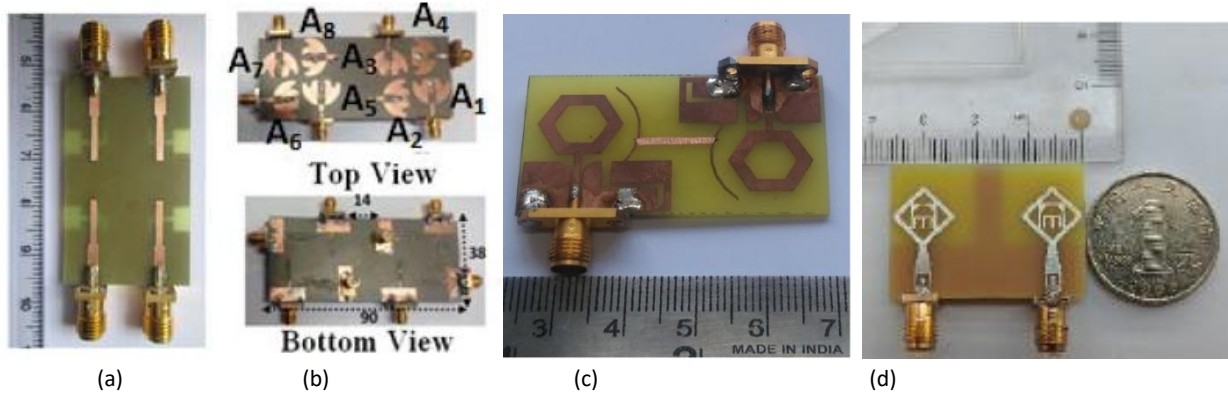


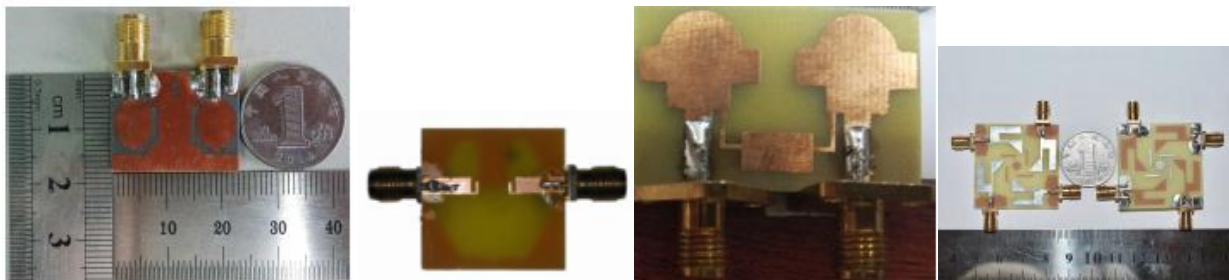
Figure 8. Different MIMO Antennas (a) Stepped Slot [17], (b) Slotted monopole [18], (c) Circular Stub [23], (d) T-Shaped Floor [27]

In other ways, a UWB band with high isolation can be achieved by modification of the ground plane along with a radiating antenna patch. Some of the research work investigated the MIMO antenna diversity parameter with wide impedance bandwidth by implementing the modifying ground plane along with the radiating monopole patch as shown in Figure 9. A rectangular line patch MIMO antenna is reported for UWB applications [28]. Implementing T-shaped slots on the ground plane, it improves the impedance matching at lower frequency and reduces the mutual coupling i.e. 18 dB for the frequency range of >4GHz i.e. 4 to 10.6 GHz.



Figure 9. Compact UWB-MIMO Slot Antenna with Two Defected Ground Structures

A compact circular monopole with two symmetrical half-slots on ground and a Y-shaped slot at the center of the common ground plane is investigated for achieving the UWB and high isolation in MIMO antenna applications [29]. The measured impedance bandwidth is from 3 to 12.4 GHz and isolation of >15 dB at lower band and >15 dB at higher frequency band. Similarly, other modified ground plane MIMO antenna such as L-shaped radiator with modified ground plane [30], monopole with F-shaped stubs on ground plane [31], half planar radiator with T-shaped ground plane and end fired monopole with tapered slot on bottom of the substrate [32] have been investigated for achieving UWB band with high isolation in UWB MIMO antenna applications. Furthermore, different shaped radiating elements like triangular monopole and modified circular monopole have been presented for UWB MIMO antenna applications [33-34]. Here, the neutralization ring is used for the enhancement of isolation between radiating element ports. The detailed outcomes of the implemented techniques MIMO antenna are reported in Table-1. In current research work, the U-shaped patch with defected rectangular ground structure is reported for UWB MIMO antenna applications [35]. In order to improve isolation, a fan shaped decoupler is implemented on the ground plane. The corresponding prototype is presented in Figure 10. Comparison of MIMO antennas with their parameters are tabulated in Table 1.



(a) (b) (c) (d)
 Figure 10. Different MIMO Antenna Structure (a) Half Slot [29], (b) Modified Ground [30], (c) Neutralization Ring [34], (d) DGS with FAN Shaped [35]

Table 1. Comparison of MIMO Antennas with their parameters

Ref	MIMO Elements	Antenna Type	Bandwidth Techniques	Isolation Techniques	Bandwidth (GHz)	Gain (dBi)	Isolation (dB)	ECC	Applications
11	1×2	Mod. Monopole	Monopole	Perturbed strips	2.82 - 16.2	6.86	>22	0.08	Wireless Comm.
12	1×2	Sierpinski carpet fractal	Fractal shaped	Mod. Ground	3 - 12.6	4.48	16.3	0.05	Wireless Comm.
13	2×2	Half-Circular Monopole	Quasi-self-complementary	Monopole complement	2.19-11.07	6.5	<-20	0.025	Wireless Device
14	1×2	Yagi Antenna	Element Arrangement	..	4.18-6.58	6	<17	0.0568	Wireless Access Points
15	1×2	Semi-ring	Element with Amplifier	..	1.8-5.5	14.1	<20	0.33	Portable Wireless Device
16	1×2	Staircase Patch	Coplanar strip-line with patch	..	3.1-10.6	5.2	<-20	0.16	Wireless Device
17	2×2	Monopole	Microstrip feed Stepped slot	stepped slots	3.1-12		<22	0.01	Portable Wireless Device
18	2×2	Annular Ring Monopole	Slotted monopole	..	3-15	5	<20	0.5	Wireless Comm.
19	1×2	Mod. Triangular Monopole	Monopole with components	..	1 - 4.5	2.65	<12.5	0.89	Handheld and Portable Devices
20	1×2	Fence-type structure	L-shaped parasitic	decoupling structure	3.4-11	6	>25	0.004	Handheld and Portable Devices
21	1×2	semicircular slot-loaded monopole	Monopole with staircase ground	Slots on ground plane	2.4-11	2	>20	0.02	Automotive, windshields of the car
22	1×2	Monopole Antenna	Taper impedance adapter	L shaped strips on ground	3.1 to 20	\	>20	0.15	Wireless Communications
23	2×2	Hexagonal Ring Monopole	Tapering slots of CPW feed line	Circular arcs stubs	3-12	3	>20	0.2	UWB-WBAN applications
24	1×2	Mod. Rect. Monopole	Meander-line EBG	EBG in ground	3.1-10.6	4	>14	0.02	Wireless Communications
25	1×2	Frog-Shaped	T-shaped floor	T-shaped slots	3.05 - 13.38	5.8	< -17	< 0.007	5G applications
26	1×2	Mod Rect. Monopole	"A" shaped slots	..	2.3-21.7	10.29	16.31	< 0.001	energy harvesting
27	1×2	Racket-shaped monopole	Cross slots and T-shaped floor	T-shaped floor	2.74 - 14.8	5.4	> 20	< 0.032	Comm. Sys
28	1×2	Monopole	T- shaped slot	Line slot on ground	3.1-10.6	3.8	<18	0.004	Wireless Device
29	1×2	Half Slot Monopole Antenna	Two half slot antenna with Y slot	..	3-12.4	4	<15	0.015	Portable Wireless Device

30	1×2	L-Shaped Radiator	Modified ground plane	..	3.5-11	4.91	<17	0.01	Wireless Comm.
31	1×2	Monopole	F-shaped stub	Stub on ground	2.5-14.5	4.3	<20	0.04	Wireless Comm.
32	1×2	Half-planar radiators	T-shaped ground stub	T-shaped ground stub	2.9 - 12	3	<15	0.3	Wireless Comm.
33	2×2	Triangular monopole	Neutralization ring	Neutralization ring	3.1-17.3	1.5	>15.9	0.1	Wireless Comm.
34	1×2	Mod. Circular Monopole	Neutralization ring	Neutralization ring	3.52-10.08	2.91	>23	0.039	Satellite Comm.
35	2×2	U-Shaped patch	DGS and FAN shaped	Fan Shaped decoupler	2–11.08	6	> 15	0.04	Comm. Sys

MIMO Antenna In-terms of Real-Field Applications

The utilization of MIMOs based on implementation of different techniques and modification of radiating patch geometry and ground plane are quite important from the antenna designer and research point of view, but cognitively it is incomplete without a real field of potential applications [36]. By taking the above points, the authors have highlighted the potential applications from the instances available in the open literature survey. The potential applications of the different MIMO antennas are presented in Figure 11.

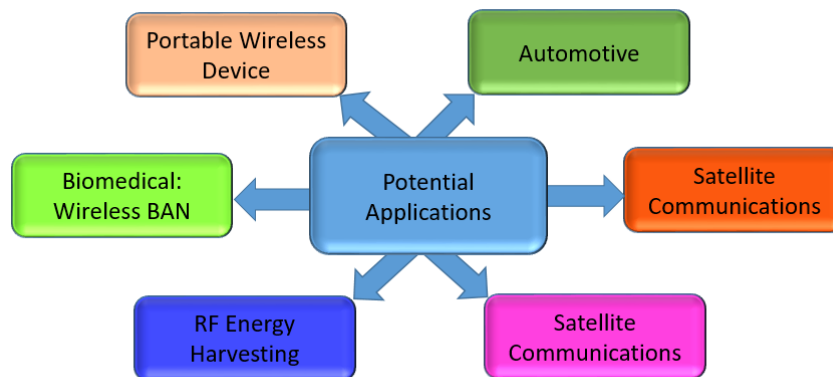


Figure 11. Potential applications of MIMO antenna

Conclusion

In this review article, a complete state-of-the-art is presented to highlight different techniques that essentially helps in achieving the ultra-wideband with better isolation in MIMO antenna. This article highlights the basics of MIMO antenna and state-of-the-art developments of MIMO antenna in terms of UWB with isolation and multiband with isolation over the last few years. Furthermore, real field potential application of MIMO antenna is presented as per the open literature survey.

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