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Ayman Mohammed Ibrahim, Imran Mohd Ibrahim, Noor Azwan Shairi

Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia

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Review Isolation Techniques of the MIMO Antennas for Sub-6

***Abstract**. The MIMO antenna is at the core of the wireless technologies currently available. Designing MIMO antennas on a limited space requires different approaches to reduce mutual coupling, otherwise, efficiency, envelope correlation coefficients, diversity gain, radiation patterns, gain and isolation will be greatly affected. Various isolation techniques have been introduced in the past five years in the previous literature to improve the performance of MIMO antennas. This review paper shows an extensive thorough reported of the envelope correlation coefficient, efficiency, Isolation, size, number of ports and isolation techniques in compact MIMO antennas to various bands.*

***Streszczenie.** W artykule przedstawiono różne techniki izolacji w antenach MIMO o małej powierzchni. Analizowano współczynnik obwiedni, skuteczność, techniki izolacji, wymiary, liczbę portów. (**Przegląd metod I technik izolacji w antenach MIMO**)*

Keywords: Envelope correlation coefficient (ECC), Isolation, MIMO antenna, Mutual coupling, Sub-6 band.
Słowa kluczowe: Anteny MIMO, techniki izolacji, współczynnik obwiedni

Introduction

Over the past three decades, improvements in cellular communications standards have dramatically altered the construction of antennas. Two main parts are included in this development. First, it is the interest of users, which consists mainly of ergonomic and aesthetic considerations, and secondly, the introduction of different spectra in line with evolving regulatory standards. Antenna design is one of the many difficult requirements for mobile system designers[1]–[3]. The rapid growth of mobile wireless systems requires multi-band, broadband, or even broadband antennas to cover the interoperability of mobile services and reduce system complexity. Additional demands for portable antennas include small size, ease of integration into the portable chassis, and coexistence with and support for MIMO systems. MIMO is one of the key elements that support 5G technology in achieving better bandwidth compared to 4G and LTE systems[4]–[6]. This technology provides additional system capacity while increasing the number of antenna elements, without the need for additional frequency or power spectrum. A high-performance MIMO system requires high isolation for each element and a low envelope correlation coefficient between them. However, this needs to be spaced between items, which is difficult to find in mobile devices as it is ideally designed to be compact antenna design[2], [6], [7].

Methods of Isolation Techniques

In this section, a survey of isolation techniques to reduce mutual coupling will be introduced. The study will focus on some important designing parameters such as isolation, envelope correlation efficient, efficiency, and size. In this study, describes different MIMO antenna design and isolation techniques. Addition, it is reviewed of MIMO antenna that has been reported by various researchers during the last five years. The isolation methods different for MIMO systems have been reported in the literature. They are grouped into five main categories in this study with a variety of other technologies used, two of them and geometry used in MIMO antenna design.

1. Parasitic Elements Technique

The parasitic elements (PE) antennas use two orthogonal modes to give a wide impedance bandwidth by coupling either in the ground plane or in the radiating patch. In PE technique, an additional coupling path is used to increase the isolation between the antennas. Besides, one coupling path opposes the signals coming from another coupling path, which leads to an increase in isolation. The main benefits of parasitic elements antennas are size, simplicity in design and convenient production using either a printed circuit board technology or waveguides [8], [9].

In [10], the design consists of monopoles, two symmetric antenna elements fed by two ports port one and port two. Each of the antenna elements is separated by a distance G = 16mm. Each port of the MIMO antenna comprises a staircase shaped radiator with a short-trip from below. It is noted that because of the low distance between port1 to port2. There is an extremely large mutual coupling between the radiators; this leads to reduced isolation. Besides, to increase isolation by placing a metal strip of length 25 mm and width 0.4 mm. This metal strip acts as a reflector and acts as a coupling element between each of the radiating ports. Both two antenna elements are printed next to the metal strip on the patch plane of the FR4-substrate. Hence, high isolation of -20 dB is achieved. In [11], each MIMO antenna element is achieved by designing a stepped with different echo frequencies. The MIMO antenna comprises a stepped-slot that is fed by a 50-ohm stepped microstrip line to get wide impedance bandwidth. In Fig.1, this design consists of a four-port open ended slot antenna is achieved by creating a stepped slot, and which generates a wide electric field in opposite directions. It leads to the little overlap between the impedance bandwidth. The resonance mode can be switched from one to another due to the stepped slots of the microstrip line, where each slot acts as a resonant element. Table1 shows another number of designs recently published for the parasitic elements technique.

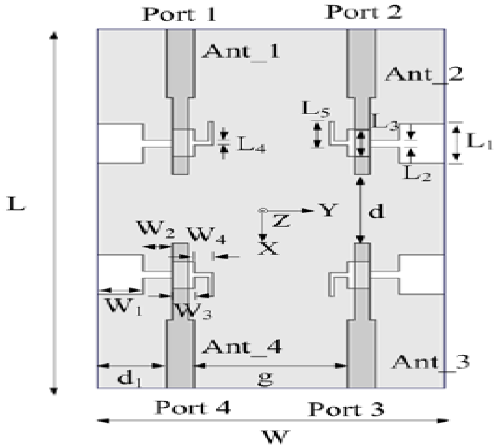

Fig. 1: Geometry of the MIMO antenna [11].

Table 1: Previous literature review of parasitic elements techniques for MIMO antennas.

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[10]	25×30	3.1-10.6	> 90	<0.16	< -20
[11]	42×25	3.2-12	> 80	<0.01	< -22
[12]	22×36	5.15-5.85	60-80	<0.1	< -15
[13]	26×40.5	3-8.5	82-88	< 0.4	< -15
[14]	80×100	1.5-2.6	68-72	<0.15	< -15
[15]	105×125	2.3-2.9	> 68	<0.15	< -15
[16]	22×24.3	3-10.6	> 82	<0.42	< -15
[17]	85×85	2.35-2.85	85-90	<0.03	< -17
[18]	32×36	3-4	65-70	<0.02	< -20
[19]	200×200	0.85-0.95	75-82	<0.01	< -35
[20]	120×60	1.6-2.7	80-90	< 0.2	< -12
[21]	75×150	3.4-3.8	65-80	<0.05	< -15
[22]	140×120	2.3-2.56	> 79	<0.01	< -14
[23]	24×20	7.6-8.1	> 80	<0.07	< -21
[24]	65×65	3.1-17.5	20-80	<0.07	< -20
[25]	140×120	2.25-2.7	> 57	< 0.2	< -14
[26]	40×36	4.5-6.37	63-71	<0.05	< -19

2. Decoupling networks techniquwe

Mutual coupling (MC) is the interaction of the electromagnetic (EM) field between two antennas. It improves the radiation pattern, the voltages of the receiving elements and antenna element matching characteristics. The isolation can be increased between antenna elements by using a decoupling networks (DN) technique. In this technique, the adjacent input ports are decoupled by providing a negative coupling such that it cancels the coupling caused between the adjacent antennas [27].

In [28], a decoupling network technique is used to increase the isolation between two dual band antennas. By designing the decoupling network, which consists of two open loop square ring resonators. This design is used for two dual-band antennas operating in the bands 2.5-2.4 and 5.15-5.35 GHz, which achieve less than 20 dB with an ECC < 0.02. Table2 shows another number of designs recently published for the decoupling network technique.

In [29], the indirect coupling is achieved through a decoupling network consisting of two sections of transmission line and two-directional couplers. These couplers are connected by two parts of the transmission line of length 25.4 mm.as shown in fig. 2. Part of the input signal from port1 can be coupled with port2, introduce indirect coupling and phase-controlled, which is applied to cancel the direct coupling caused via surface and space waves between antenna elements.

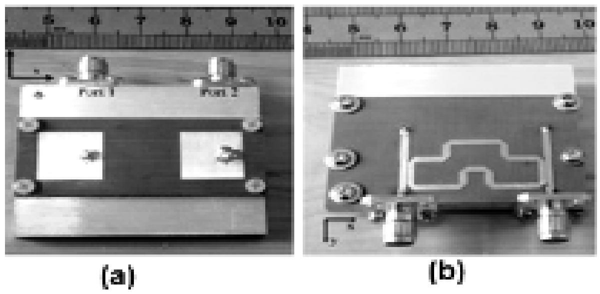

Fig. 2: Fabricated MIMO antenna with DN (a) Top view, (b) Bottom view [29]

Table2: Previous literature review of decoupling network techniques for MIMO antennas.

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[30]	25×60	2.4-2.5	50-60	<0.17	< -11
[31]	80×80	1.8-2.65	> 85	<0.001	< -15
[32]	72.4×20	2.18-2.6	66-70	<0.001	< -20
[33]	100× 52	0.7-0.9	55-70	< 0.14	< -16
[34]	77.6×63	4.03-5.4	86-92	< 0.15	< -13
[35]	24 × 24	3.1-10.8	80-90	<0.002	< -20
[36]	50×61.5	2.35-2.5	51-82	<0.04	< -20
[37]	40×100	3.5-3.6	45-60	<0.03	< -15
[38]	74×47.3	2.46-2.7	20-30	<0.004	< -12
[39]	55×65	2.4-2.5	60-65	<0.15	< -15
[40]	75×150	3.4-3.6	> 60	<0.012	< -19
[41]	105×50	4.03-5.4	65-68	<0.15	< -27
[42]	40×40	3.4-3.58	> 79	<0.04	< -18
[43]	35×36	3-9	88-92	<0.01	< -25
[44]	75×150	3.4-3.6	> 60	<0.002	< -20

3. Metamaterials technique

Meta-materials (MM) are materials that have permeability or negative permittivity. Meta-material based antennas are divided into two types. One that makes use of Double Negative DNG, Epsilon Negative ENG, or μ-negative MNG substrate is called Meta-materials based antennas[5], [45], [46]. Antenna technique for metamaterials, the MIMO antenna configuration is formed by assembling composite materials, for example, plastics and metals. The repetition pattern of the material makes it able to process electromagnetic waves. Also, the equivalent surface interface of a negative permeability is also worked as a meta-material in increasing isolation in the MIMO antenna system [47].

In [48], the design of the MIMO antenna metamaterial with a reversal composite right-left-handed configuration antenna is presented. The MIMO antenna is designed to cover 5.6-5.7 GHz for wireless applications. The two antenna elements are created utilizing a single reverse unit left cell to isolate high mutual coupling in a close separation, as shown in Fig.3. The metamaterials are used to two antennas to reduce the isolation of about -27 dB. Table3 shows another number of designs recently published for the Meta-materials technique.

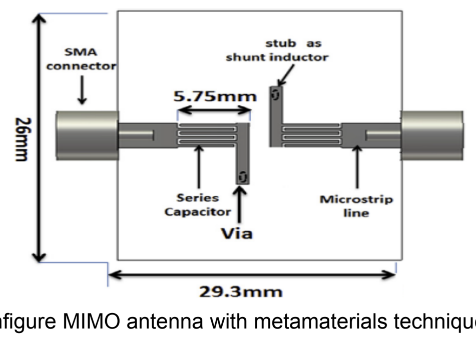

Fig.3 : Configure MIMO antenna with metamaterials technique [48].

Table3: Previous literature review of Meta-materials techniques for MIMO antennas

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[49]	30×44	2.38-2.5	81-85	<0.15	< -20
[50]	60×57	2.3-2.54	> 82	<0.002	< -30
[51]	35.5×71	5-5.38	50-90	<1	< -24
[52]	150×150	2.4-2.48	80-90	<0.005	< -35
[53]	125×75	0.75-0.9	38-75	<0.4	< -15
[54]	43×26	2.3-2.47	80-85	<0.1	< -15
[55]	60×85	2.4-2.5	68-78	<0.25	< -15
[56]	68×40	2.61-2.7	> 68	<0.4	< -25
[57]	15×35	3-12	> 60	<0.01	< -10
[58]	100×122	2.3-2.69	85-90	<0.12	< -15
[59]	200×100	3-3.7	30-34.	<0.15	< -25
[60]	90×90	8-10	80-90	< 0.1	< -14
[61]	40×80	4.4-8	> 70	<0.002	< -22
[62]	56×38	5.6-5.95	> 95	<0.05	< -25
[63]	137×77	5.6-5.93	> 73	<0.02	< -18
[64]	60 × 32	5.6-6.05	> 80	<0.004	< -24

4 Neutralization line techniquew

Isolation among antenna elements can also be improved by using a neutralization line (NL). The current in the input element is taken at a specific location where the impedance is minimum and the current is maximum, and then its phase can be reversed by choosing an appropriate length of NL. This reverse current is then fed to the nearby antenna to reduce the amount of coupled current [65]. In the design of MIMO antenna, The NL is a small width metal structure, which improves insulation between the antenna elements and solves the problem of mutual coupling. The size, direction and shape of the NL depend on the antenna elements. This structure is simple and easy to implement. Nevertheless, finding a path to the design and implementation of NL is not simple[66].

In [67], the dimensions of the antenna array are 103.2×60 mm^2 and printed on an FR4-substrate with a loss tangent of 0.02 and relative permittivity of 4.4. Two MIMO antennas are using a distance of d = 3.2 mm to increasing isolation between them. In Fig.4, a two-design MIMO antenna with a simple structure was proposed to increase isolation between them, and two neutralization lines link the two elements. The neutralization line's dimensions are optimized to gets low mutual coupling between the two ports. The L5 neutralization line affects the mutual coupling of the array. The coupling coefficient of the MIMO with NL differs significantly in the upper band than the lower band with the length of the L5 changes, and the NL has connected between the two patch planes.

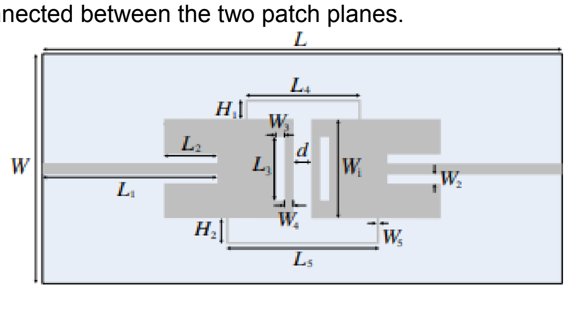

Fig. 4: Fabricated of MIMO antennas with neutralization lines [67].

In [68], the researchers designed a single plate of MIMO antenna with π-shape built-in port isolation, operating in the 5.15-5.58 GHz band. The MIMO antenna was a symmetrical structure that consisted of the FR4 substrate, and the base radiating element was a π-shape structure on patch plane. The π-shaped structure had a small size (24 × 28 mm2) and high isolation of less than -16dB with an ECC value of less than 0.05, and efficiency of 60% at 5 GHz band.

In [69], The hexagonal band antenna with a NLs was used in the design to get on a reduce ECC value. A NLs with an F-sharped antenna was used to produce more than 15dB of isolation. The design covers GSM 1800/1900MHz, Global Mobile Communications, LTE 2300MHz.

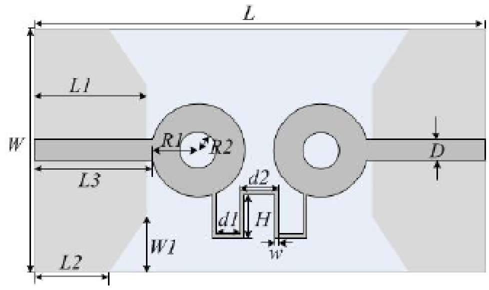

Fig. 5: The geometrical of the MIMO antenna [68].

In [70], a monopole antenna array is proposed, By a triangle on the ground plane and cutting a circle in the middle of each patch plane, the radiation characteristics and the reflection coefficient can achieve great improvement. In Fig. 5, a NLs is added between the two correction plane ports, which helps increase the isolation between the antenna ports, which affects the change of the length of the H parameter to the isolation value and frequency band. Table4 shows another number of designs recently published for the neutralization line technique.

Table4: Previous literature review of neutralization line techniques for MIMO antennas

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[68]	24 × 28	5.15-5.8	> 60	< 0.05	< -16
[71]	200 × 150	3.4–3.84	> 50	=0	< -16
[72]	140 × 70	3.4 - 3.8	40-57	< 0.1	< -10
[73]	150 × 200	3.4–3.8	72-86	< 0.1	< -12
[74]	150 × 57	3.4 - 3.6	30-53	< 0.3	< -10
[75]	55 × 100	1.8–3.84	> 69	< 0.14	< -16.5
[76]	130 × 70	3.4–3.6	56-70	< 0.5	< -11
[77]	80 × 100	2.3-2.57	62-72	< 0.3	< -14
[78]	150 × 75	3.4 - 3.6	40-52	< 0.15	< -10
[79]	60 × 60	2.3 - 2.9	67-84	< 0.005	< -20
[80]	54 × 30	5.6-5.9	= 45	< 0.02	< -20
[81]	75.19×75.19	3.1-17.3	49-83	< 0.1	< -13
[82]	40 × 38	5.2-5.84	93-97	<0.005	< -20
[83]	46 × 27	3.6-17.6	78-96	<0.018	< -18
[84]	250.42×12.9	2.3-2.4	> 90	<0.0.01	< -21
[85]	48 × 34	3.52-10	70-79	< 0. 5	< -22
[86]	124 × 70	3.3-3.6	> 40	< 0.15	< -15
[87]	150 × 75	3.4-3.6	> 50	< 0.15	< -15
[88]	35 × 50	1.2-6	45-65	< 0.18	< -25
[89]	24 × 49	5.5-6	> 62	< 0. 03	< 12.5

5 Defected ground structure techniquew

The defected ground structure (DGS) has represented the slots or dumble-shaped defects integrated on the ground plane of antenna. [90]. The DGS is used as a technique for improving several parameters of the MIMO antenna systems, including low gain, cross-polarization, and narrow bandwidth. Moreover, It is a technique that significantly contributes to increased isolation between elements [91]. The current generated at a ground plane can be coupled with adjacent elements causing a high coupling that further isolation the MIMO antenna system, which can be minimized by modifying the ground plane. It works as a band-stop filter and inhibits the coupled fields between the adjacent antenna elements by decreasing the current on the ground substrate. The defected ground structure is classified according to band stop characteristics that prevent the propagation of electromagnetic waves. The defective ground structure is located below the transmission-line which eliminates the electromagnetic fields around the defect. The electric fields near defected ground structure lead to a higher to the capacitance effect, and the superficial currents around a defect cause an inductance effect. The mutual coupling was reduced using slots on the ground plane, and etching slits called a DGS, but a large ground plane is needed to achieve this reduction. Moreover, this technique has disadvantages in practical implementation due to its complicated ground structures[9].

In [92], the MIMO-based antenna is explained on the ground square structure to increase isolation; the structure of the array antenna has two square radiating patch that supports orthogonally polarized half-wavelength modes. Besides, L-shaped slots from the inside are included to make this structure small. Inside ring ports P1 and P2 or Inner patch, feed excite TM01 and TM10 modes. Also, there are two ports P3 and P4 outside the ring and operate in orthogonal positions with higher order.

In [93], a periodic MIMO antenna at the patch plane was designed using DGS technique to reduce mutual coupling. The periodic S-shaped DGS induced current between patch elements and prevents the electromagnetic far-field significantly, as shown in Fig. 6. The antenna elements in the band (2.55 - 2.65) GHz were covered at a center frequency of 2.57 GHz, and the isolation of less than -20 dB was achieved with an envelope correlation coefficient of less than 0.1.

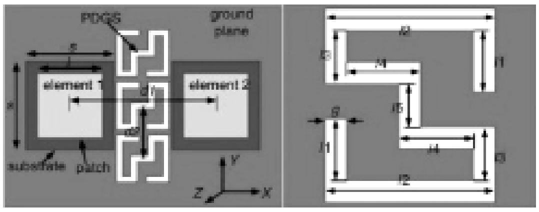

Fig. 6: The periodic S-shaped MIMO antenna with defected ground structure[93].

Table5: Previous literature review of defected ground structure techniques for MIMO antennas

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[94]	38.5×38.5,	5.03-5.9	34-75	< 0. 08	< -10
[95]	50 × 100	2.3-2.6	40-80	< 0. 04	< -20
[96]	60 × 160	0.69–0.9	> 80	< 0.075	< -25
[97]	100 × 60	2-2.26	> 70	< 0. 067	< -11
[98]	22 × 26	3.1-11.8	> 85	< 0.03	< -20
[99]	120 × 45	1.89-2.5	> 70	< 0. 098	< -12
[100]	17 × 42	6.6-7.6	72-90	< 0.015	< -13
[101]	45 × 25	2-12	> 70	< 0. 2	< -15
[102]	50 × 80	5.1-5.33	> 80	< 0.016	< -21
[103]	145 × 65	1.68-2.8	31-55	< 0.15	< -15
[104]	50 × 100	1.95-2.2	55-85	< 0.009	< -20
[105]	50 × 50	3-16.2	65-91	< 0.3	< -17
[106]	110 × 55	0.6- 0.9	50-70	< 0.5	< -10
[107]	80 × 80	3.1-11.5	> 90	< 0.015	< -20
[108]	60 × 120	3.2-3.9	59-80	< 0. 5	< -10
[109]	61 × 65	4.82-5.9	45-95	< 0. 4	< -15
[110]	110 × 120	1.9-3.31	82-92	<0.0002	< -15

6 Hybrid structure technique

In this section, shows some combine isolation techniques such as [111]–[115] used combine isolation techniques between defected ground structure and nebulization lines, While used merge between two isolation techniques are defected ground structure and meta-materials. There are other hybrid techniques, some of which are explained below:

In [112], a compact MIMO antenna was proposed for USB dongle application, that covered 2.4 – 2.48 GHz; 3.4 – 3.8 GHz and 4.7 – 5.83 GHz bands. The two antennas were closely spaced on a printed circuit board at a distance of about 0.094λ for minimum resonant frequency. To increase the isolation between the port elements and to get the coveted operating bands, a combination of L-shaped slots DGS, and an X-shaped NL was used. The DGS and NL were analyzed based on surface current distributions and the S-parameters. Compact MIMO antenna shows the configurations of the proposed MIMO antenna elements. It consist of two monopoles that were symmetrically printed on FR4 substrate. The antenna elements of the proposed MIMO antenna consist of two arms (arm1 and arm2). To achieve better isolation between them, the connection point of the NL with radiating elements was optimized and the effect of MC technique were applied to the S-parameters. The MC at the underside of the frequency was significantly lower than -5 dB in comparison to the absence of MC technique. Isolation was effectively improved by integrating the DGS with NL. Hence, the required frequency bands and isolation between the antenna elements was greater than -14 dB.

In [115], the antenna is designed with dimensions of 40 x 50 mm^2, and a multi-band antenna is presented in a circle-shape with a dumbbell-shaped parasite for all wireless applications. The presented MIMO antenna includes a circular-shape radiating patch with two rectangular slits, a U-shaped slot, and the neutralization line consists of two circuits connected by a straight line, as shown in Fig.7. Table6 shows another number of designs recently published for the hybrid structure technique.

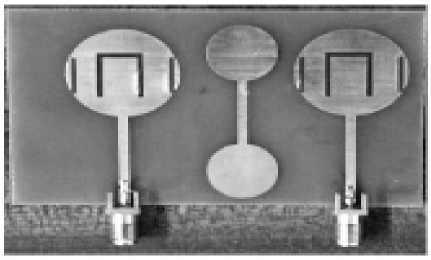

Fig. 7: Fabricated MIMO antenna with dumbbell-shaped [115]

Table6: Previous literature review of hybrid strucure techniques MIMO antennas

Ref.	Size mm^2	BW GHz	Eff.%	ECC	Isolation dB
[1]	31×31	3.15-3.55	68-71	< 0.06	< -25
[2]	26 × 46	3.4 - 4.7	78–90	< 0.08	< -21
[4]	24 × 21	4.7 - 5	> 70	< 0.016	< -18
[112]	60 × 25	3.4–3.8	52-88	< 0.16	< -15
[113]	136 × 68	3.4–3.6	50-60	< 0.2	< -10
[114]	31 × 22	5.8-6.1	> 80	<0.0002	< -42
[115]	50 × 40	3.3-3.6	27-40	<0.0014	< -25
[116]	50 × 40	5.7-5.85	82-85	< 0.002	< -20
[117]	40 × 60	5.1-6	70-81	< 0.2	< -20
[118]	40.5×40.5	5.1-5.95	5-20	= 0	< -20
[119]	64 × 45	5-6	> 80	< 0.02	< -15
[120]	40.5×40.5	3.6-3.8	40-80	< 0.035	< -17
[121]	12.5 ×37	3.6-4.2	55-69	< 0.002	< -34

Conclusion

The MIMO antenna is employed to resolve the problem of single-input single-output antennas. Also, their performance factors like efficiency, envelope correlation coefficient, isolation, gain, radiation patterns and diversity gain affected, due to the very close nearness to MIMO antenna ports. The effect in these factors is expected to the radiation properties of ground and radiators which is usually found as a mutual coupling. Therefore, the previous literature review of the last five years was presented for MIMO antenna with the impact of isolation techniques parasitic elements, defected ground structure, metamaterial, decoupling networks, neutralization line and hybrid structures were presented, with their demerits and merits to control Mutual coupling.

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***Authors**: A. M. Ibrahim, Email: ayman971972@gmail.com; I. M. Ibrahim, Email: imranibrahim@utem.edu.my; N. A. Shairi, Email: noorazwan@utem.edu.my. The address for all authors Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia.*

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