Anwer Jabbar Hasan Al-saedi[1], Jesus Carretero Perez [1]

1- University Carlos III de Madrid, Spain
ORCID: 1. 0000-0002-9522-3105, 2. 0000-0002-1413-4793

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A Review: Compact Size and Isolation of MIMO Antenna

***Abstract**. The rapid growth of wireless system required additional frequency spectrum in order to tolerate the growing telecom networks. To address such requirement, MIMO technique that target on antenna arrays and diversity is an adequate solution that would be leading to achieve the high additivity and reliability. the main objective is to design a suitable MIMO antenna with optimum specification and best results such as size miniature, wide bandwidth, high efficiency, high isolation, lower envelope correlation coefficient and reduced input reflection coefficient. All research in this paper mentioned in the literature survey is aimed to display MIMO antennas that best results of the size, envelope correlation coefficient and isolation.*

Streszczenie. *Szybki rozwój systemu bezprzewodowego wymagał dodatkowego pasma częstotliwości, aby tolerować rosnące sieci telekomunikacyjne. Aby sprostać tym wymaganiom, technika MIMO ukierunkowana na macierze antenowe i różnorodność jest odpowiednim rozwiązaniem, które prowadziłoby do osiągnięcia wysokiej addytywności i niezawodności. głównym celem jest zaprojektowanie odpowiedniej anteny MIMO o optymalnej specyfikacji i najlepszych wynikach, takich jak miniaturowy rozmiar, szerokie pasmo, wysoka wydajność, wysoka izolacja, niższy współczynnik korelacji obwiedni i zmniejszony współczynnik odbicia wejściowego. Wszystkie badania w tym artykule, wymienione w przeglądzie literaturowym, mają na celu pokazanie anten MIMO, które mają najlepsze wyniki pod względem rozmiaru, współczynnika korelacji obwiedni i izolacji.* (***Przegląd stanu wiedzy na temat Kompaktowego rozmiaru i izolacji anteny MIMO***)

Keywords: Compact, *envelope correlation coefficient, MIMO antenna, Isolation.*
Słowa kluczowe: anteny kompaktowe MIMO, izolacja

Introduction

In the previous decades, wireless communication witness considerable expansions. The antenna was primarily to development in wireless communication technology appeared. The antenna can be defined as a metallic device that works as transmitter or receiver of unguided waves. It acts as an interface between circuitry and free space and playing a vital role in the wireless communication field, it used in military and civilian system applications. As it is known. There are various types of antenna such as monopole, dipole, reflector, a slot antenna, a patch antenna and folded dipole antenna, each type of them has different attributes and applications [1]. Modern wireless communications needed a large bandwidth and high data rate because of crowded in conventional segments of spectrum, recently, a challenging task for the researcher is to design an antenna that combines both of size miniature and excellent characteristics of power consumption and cost of semiconductor have decreased significantly [2].

A proper transmission and reception can be obtained by using Micro Strip Antenna (MSA). MSA defined as a conducting patch printed on the dielectric substrate of various dielectric constant or permittivity; it has various shapes and sizes that effect on the performance of the antenna. MSA has many attractive attributes such as conformable to a planar surface, low profile, uncomplicated design, unexpansive to manufacture and robustness. Beside these attractive features MSA has a number of drawbacks such as narrow bandwidth, low gain, and poor efficiency, to address those drawbacks and obtain wide bandwidth antenna, many techniques are used, one of them is fractal geometry technique. Therefore, to design wideband antenna it needs to employ that such technique. Modern MSA must achieve both of size miniaturization and wide bandwidth while keeping antenna design as simple as possible [2].

A good antenna design played an essential role in the design of wireless communication system, international companies looking for the best design that accommodates with its products in term of size, bandwidth, gain, cost and more reliable achievement in term of capacity and quality of transmission and reception process, therefore, a proper antenna design will enhance the performance of the overall wireless communication system as [1], [2]

The rapid growth of wireless system required additional frequency spectrum in order to tolerate the growing telecom networks. To address such requirement, MIMO technique that target on antenna arrays and diversity is an adequate solution that would be leading to achieve the high additivity and reliability. Also, dealing with MIMO antenna technique is aiming to exploit its benefit which can be 5G multi-band, or even broadband antennas to cover the interoperability of mobile services and thus, reduce system complexity. Additional demands for portable antennas include smaller 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 to achieve better bandwidth compared to 4G and LTE-Advance (LTE-A) systems(Wiley, no date). 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 antenna 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.

Mutual coupling

It is the description of the absorbed energy by neighboring antennas when excited. Also, it tends to change the system element's radiation patterns, input impedance and reflection coefficients. The Mutual coupling denoted by MC between N and M is given by [3]:

$$MC_{ij} = \exp\left(-\frac{2d_{ij}}{\lambda}\ (\alpha + j\pi)\right), i \neq j \tag{1}$$

where S is the parameter which controls the coupling, λ is the wavelength and d is the distance separated between N and M. Practically, the mutual coupling depending not only upon antenna system geometry but also on the elements' excitation. It is worth mentioning, minimizing mutual coupling does not correlate automatically to a lower value. It may be a collinear deploying pair don't radiate into each other which mean that they have low mutual coupling meanwhile they have polarization characteristics, same beam and high correlation. In reality, the mutual coefficient must be reduced as much as possible on smartphone but the following factors must be taken in account [4]: Firstly, neighboring Scattering Objects: The careful design of the smartphone or any device can minimize the coupling cause significantly is produced by the scattering materials presence near to antenna. Secondly, common Ground Plane Currents: The usage of differential antenna design, i.e. dual polarized port antenna, which depends on its work against itself instead of the ground plane. Lastly, The Directional Radiation Between Antennas: Choosing an antenna with resonant modes can minimize the directional radiation between antennas by creating a null in the field patterns of their directions and this is difficult to achieve when the antenna's near fields lie in each other.

Envelope correlation coefficient (ECC)

It is defined as an important and interested parameter between two antennas, i.e. when evaluating diversity reception with the potential improvement due to its association with the spectral efficiency losses and performances of MIMO system degradation. The ECC is calculated by scattering parameter (S-Parameter) which is given by Equation 1 [5]:

$$(2)\quad \rho_{ij}(e) = \frac{\left| \sum_{n=1}^{N} S_{ni}^{*} S_{nj} \right|}{\sqrt{\left(1-\sum_{n=1}^{N} |S_{ni}|^2\right)\left(1-\sum_{n=1}^{N} |S_{nj}|^2\right)}}$$

where i (1 to N) and j (1 to N) are antenna ports, n is the number of radiating elements, Sni and Snj are scattering parameters of antenna elements. Fig.1 shows the ECC Calculation Methods and Performance Measurement of MIMO Antenna Designs [5].

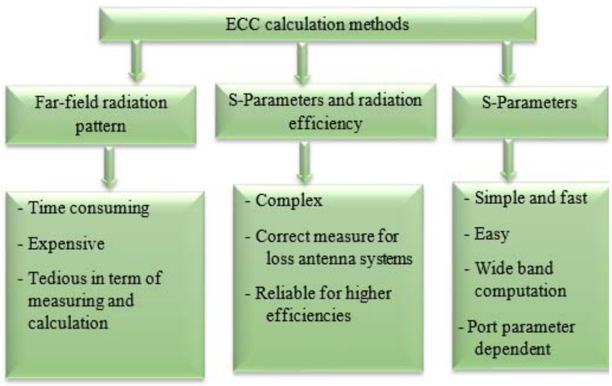


Fig.1: ECC Calculation Methods and Performance Measurement of MIMOAntenna Designs[5]

Isolation techniques

Different isolation methods for MIMO antennas, that have been reported in the recent literature, are also reported. They are grouped into main categories are:

- **Defected Ground Structure Technique:** The basic element of Defected Ground Structure (DGS) is a resonant gap or slot in the ground metal, placed directly under a transmission line and aligned for efficient coupling to the line[6].
- **Neutralization Line Technique**: By using Neutralization Line (NL), the isolation between the antenna elements can be improved. This is possible because the current of the antenna elements is neutralized. The current at the input element has been taken at a specific location when the impedance is minimum and the current is maximum and thereafter by choosing the appropriate length for the NL its phase is revised. By feeding this revised current to the neighboring antenna, the coupled current can be decreased[7].
- **Decoupling Networks Technique**: The electromagnetic (EM) field interaction between two antennas is known as MC. It improves the radiation pattern, antenna element matching properties, and receiving element voltages. Using a Decoupling Networks (DN) technique, the isolation between antenna elements can be enhanced. The adjacent input ports are decoupled in this approach by creating a negative coupling that eliminates the coupling between the neighboring antennas [8].
- **Parasitic Elements Technique:** The Parasitic Elements (PE) antennas use two orthogonal modes of coupling in the ground plane or in the radiating patch to provide a large impedance bandwidth. An additional coupling path is used in the PE technique to improve the isolation between the antennas. Furthermore, one coupling path opposes signals coming from another coupling path, resulting in increased isolation. The simplicity of design, size, and ease of fabrication utilizing either printed circuit board technology or waveguides are the key advantages of parasitic elements antennas[6].
- **Metamaterials Technique:** Metamaterials (MM) are materials that have permeability, negative permittivity, or both. There are two types of metamaterial antennas. One that uses Double Negative (DNG), Epsilon Negative (ENG) or μ-Negative (MNG) substrate. The other one uses unit cell such as the Split Ring Resonator (SRR). Composite materials, including as plastics and metals, are used to create metamaterial-based MIMO antennas. The material's repeating pattern enables it to process electromagnetic radiation. In addition, the corresponding surface interface of a metamaterials negative permeability medium helps in the reduction of MC and increaseS in isolation among antenna elements in the MIMO antenna system [2].
- **Hybrid Structure Technique:** In this section, studies that combined different isolation techniques in MIMO antennas are discussed. Some researchers, such [2]as merged DGS and metamaterials for isolation. In addition to this, while [6][7] used combined DGS and NL isolation technique between antenna elements, there are other hybrid techniques (HT).

Table 1: Advantages and disadvantage of isolation techniques

Tech.	Advantage	Disadvantage
DN	- Simple technique. - Enhancement far field properties.	- Sometimes an extra area is needed.
PE	- Control of mutual coupling. - Excellent ECC.	- band shifts when adding parasitic-elements
MM	- Improve size about of 18%. - improve channel capacity.	- Lower efficiency of 30% for substrate-antenna.
DGS	- The DGS gives small antenna size - high isolation	-Low gain
NL	- Good Impedance Matching(IM) - high isolation and lower ECC	- F_L band has wider BW when compared with F_H band.
HT	- The HT offers a compact antenna size - Good Impedance Matching - High isolation and lower ECC	-Low gain

Table 1 shows the disadvantages and advantages of isolation techniques. In this work, the hybrid technique for MIMO antennas, to achieve good impedance matching, compact antenna size and good antennas isolation with envelope correlation coefficient FL band has wider bandwidth when compared with FH band. However, it other isolation techniques could be used to improve channel capacity, ECC and far-field characteristics.

Related for MIMO antenna systems

The researchers Jetti and Nandanavanam [8] designed an antenna with two slots on the ground to achieve a defected ground structure technique. This design increased the isolation between MIMO elements in the ultra-wideband due to the presence of a trident-shaped strip on the antenna feed-line and the bands (5400-5860) GHz and (7600-8400) GHz were covered. Besides, it achieves isolation greater than 20. Furthermore, slot on ground plane presented more suitable impedance matching properties in lower frequency bands. Fig.2 showed the fabricated MIMO antenna.

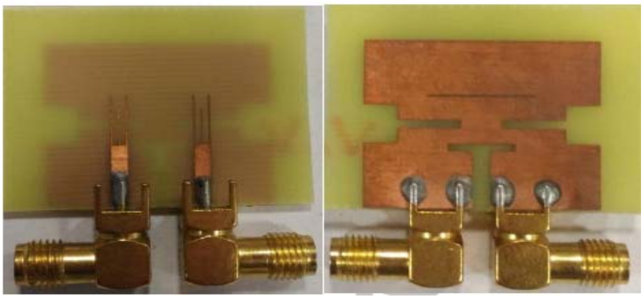


Fig.2: Geometry of MIMO antenna with defected ground structure technique [8]

A study by Wang, Member and Du [9], a MIMO antenna was designed for a dual-band that has two NL cross and similar antenna elements. The antenna elements included a parasitic ground plane, which is also a branch network containing an inner branch and an outer one printed on the bottom layer. Besides, antenna elements included a driven branch, which was on the top layer of the printed circuit board. The main part of the outer branch uses two expanded copper sheets located on the upper corners of the printed circuit board (PCB). Cross NLs were created using 4 vias. Hence, any NL finds a link through vias to the nodes of the non-corresponding antenna element at both end. The driven branch parasitic ground plane at the antenna terminal generates multiple-resonance modes. Furthermore, to mitigate the effect of cross-coupling on the low-frequency intersecting NL between the two antenna elements. However, to minimize cross-coupling at a frequency higher than 2.45 GHz, the parasitic ground branch was designed. Thus, the parasitic ground branch and the cross-neutralization help to compensate for the mutual coupling together with the vias and the driven branch.

Zhang and Pedersen [10] introduced a MIMO antenna with a circular monopole printed at a distance of 2.2 mm on the substrate. The NL is connected between two monopoles on the patch plane, as shown in Fig.3. Isolation was reduced by adding a metallic circular disc and two metal bands. The disc provided the decoupling current paths with various lengths to reduce the coupling current on the ground substrate. The circular aperture printed on the antenna reduced decoupling frequencies to 5 GHz. By adding a wideband NL at the ground substrate. The NL is connected with two antennas to reduce the bandwidth that still covered the UWB-MIMO bandwidth from 3.1 GHz to 1-5 GHz, producing isolation of about -22 dB.

Shin, Kibria and Islam [11] found that low ECC value was achieved by a hexagonal band antenna with a NL. A NL with an F-sharped antenna was used to produce more than 15 dB of isolation. The design basically covers GSM frequency 1.8 or 1.9 GHz, Global Mobile Communications, LTE 2.3 GHz.

Another study by Yu et al. [12], a monopole antenna array was proposed. The researchers achieved improved radiation characteristics and reflection coefficient by fabricating a triangle on the ground plane and cutting a circle in the middle of each patch plane. A NL was added between the two correction plane elements, which helped to increase the isolation between the antenna elements (20 dB).

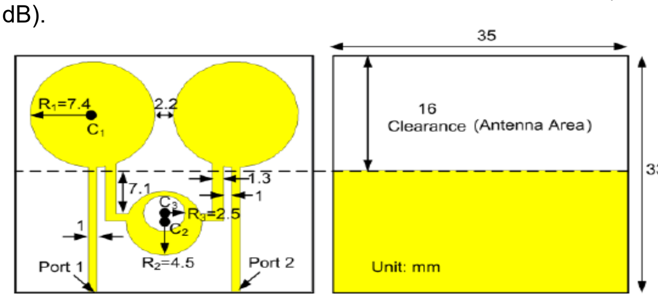
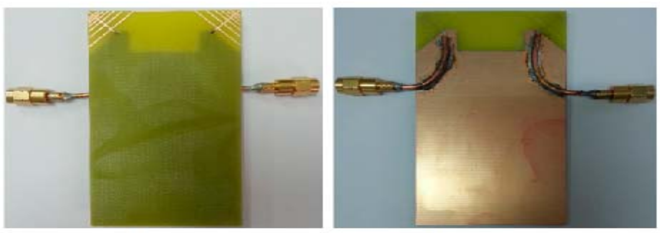


Fig.3: A Geometry of Circular Monopole printed MIMO Antenna [10]

Toktas [13] proposed a novel MIMO antenna, based on log-periodic dipole array for mobile smartphones. The antenna covered frequencies in the range of 1.86 to 3.84 GHz and was compatible with WiMAX, WLAN, LTE, and GSM. The MIMO antenna was composed of two symmetrical and orthogonal radiating elements and a NLs. The radiating element was composed of a log-periodic dipole array with a series of printed dipoles joined to a microstrip line, as shown in Fig.4. Rectangular and triangular cutting operations were performed at ground plane, carried out by the log-periodic dipole array, to increase the isolation. The MIMO antenna was connected to the NL to increase the isolation between the radiating elements. Besides, in cases where there was no NL, the adjacent antenna elements were perpendicular to each other thus causing lower current. They further reported that the density of the current distribution was increased approximately symmetrically between the longer dipoles and the shorter dipoles to the center microstrip fed line of the log-periodic dipole antennas. Hence, the decrease in surface currents from one element to another was caused by NL. Further, the NLs played an important role in decreasing the current on the log-periodic dipole antennas monopoles facing to each other.



(a) front view (b) back view

Fig.4: Prototype Antenna Array with NLs [13]

Another study by Cheng et al. [14] proposed a new MIMO antenna, a new polarization conversion isolator was suggested to improve the isolation between two antenna elements. The reduction of mutual coupling was achieved by controlling the polarization of the coupling field. To improve the performance of the cross-polarization, four circular slots were drilled with an increase radius on the ground plane. The trade-off between the cross-polarization and mutual coupling could be adjusted with the radius of the slots. A fabricated prototype was measured, and the results demonstrated excellent cross-polarization and mutual coupling properties, while the isolation of 19.6 dB was achieved.

The researchers Kayabasi et al. [15] suggested a novel MIMO antenna, four-port multi polarized ultra-wideband MIMO antenna system with a novel isolation technique. This antenna consisted of four triangular elements and a neutralization ring technique. The antennas were placed consecutively in an orthogonal and symmetrical order. A neutralization ring technique was achieved by combining a straight line and a rectangular ring that increased the isolation.

A study by Li et al. [16] presented MIMO antenna, a metal frame integrated 8×8 MIMO array, that operates in the LTE bands 43/42/41 (2496 - 2690 MHz, 3400 – 3800 MHz) for future 5G applications in smartphones was proposed. The presented 8×8 MIMO array was created by combining four symmetrical building blocks, each of which included a pair of dual-mode antenna elements with NLs connected in between. The part of the metal-frame was used to improve the effective resonant length of the MIMO antenna. The isolation was improved to less than 10 dB by using a NL.

Chou et al. [17] focused on a dual-band MIMO antenna. The proposed antenna covered two 2.4 – 2.484 GHz and 5.15 – 5.85 GHz frequency bands. The method to reduce mutual coupling was based on the NL technique. The isolation between the two MIMO antennas was increased to -23 and -16 dB in the two bands, respectively. The short distance of up to (18 mm) between the two elements lead to a reduction in efficiency and an increasing in coupling. The way to overcome this problem, the NL was introduced.

The researchers Zou et at. [18] proposed a novel MIMO antenna for both LTE and 5 G applications, eight MIMO antennas operating in the LTE (2.496 - 2.69 GHz and 3.3-3.7 GHz) bands for 5G metal-framed smartphone was presented. The introduced MIMO antenna system comprised of four identical dual antenna building blocks, with NL between two adjacent antenna elements. The antenna array achieved isolations of -10.5 dB and -11.0 dB and total efficiency (41- 54) % and (46 - 64) % in the LTE and 5G bands, respectively.

Fritz, Aguilar and Mendez [19] introduced a new MIMO antenna, the proposed design used a triangle shape at the patch plane with the NL linked between them. The length (42.71 mm) and width (1 mm) of the straight line was adjusted in such a way so as to avoid the creating a radiant line. Total length of the straight line was divided into three segments of the same length (C) and other length (E) to become the total length of NL (3C+2E) as shown in Fig.5 (b).

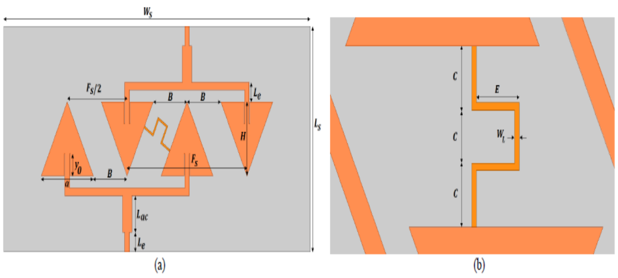


Fig.5: MIMO Antenna (a) Geometry of the Antenna (b) View of the NL [19]

A study by Gurjar et al. [20] presented sierpinski fractal MIMO antenna with two ports based on a monopole antenna. It used neutralization line technique of mutual coupling. It dimensions of the MIMO antenna 24 × 30 mm based on a sierpinski slot unit monopole antenna results in isolation less than 16.3 dB.

The researchers Kumar et al.[21] presented a MIMO mobile antenna of dimensions 63 × 63 mm with four ports based on a monopole antenna. It obtained isolation less than 18 dB with envelope correlation coefficient less than 0.005, using neutralization line technique, as shown in Fig.6.

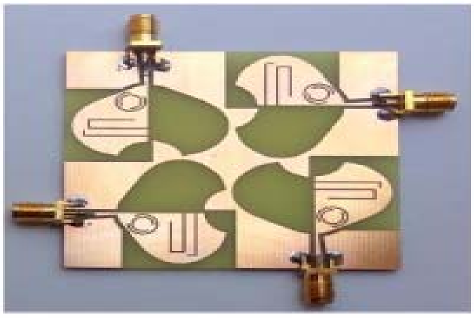


Fig.6: Fabricated prototype of SWB-MIMO TESCA [21].

Liu, Cheung and Yuk [22] have both suggested a new MIMO antenna, a small MIMO antenna with size 22 × 36 mm2 was proposed for portable ultra-wideband (UWB) applications. The proposed design consists of a T-shaped ground stub, a slot between the two square elements was used to increase the isolation, as shown in Fig.7. The stub enhanced the matching, the slot inside the stub reflect the radiations from the elements and reduced mutual coupling to achieve an isolation better than -15 dB.

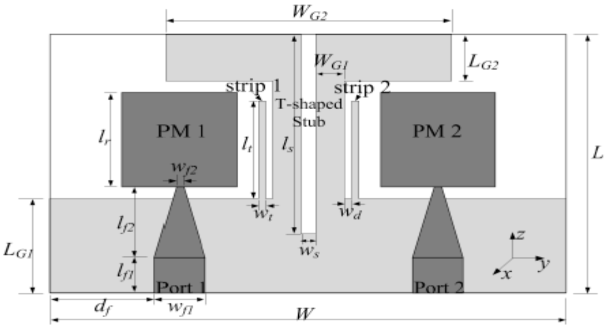


Fig.7: Geometry of the MIMO Antenna Using PE [22]

The researchers Khan et al. [23] introduced a compact MIMO antenna for ultra-wideband, design a single shared radiating element with two feedings. The compact size was achieved by a resonant stub which was joined to the ground substrate and reduced unnecessary coupled energy before it reached the other port lead to reducing the mutual coupling, and design slots in the patch plane that also helps increase isolation. The design prospects are shown in Fig.8. Meandered lines significantly reduced the overall size of the antenna. This MIMO antenna has a compact size of 24.3 × 22 × 1.6 mm3 with high isolation better than 15 dB, which makes it a great candidate for handheld devices.

Khan, Muhammad Saeed, et al. [24], To design two antenna elements with dual polarized ports. It obtained a size of 23×19 mm2 with mutual coupling – 12 dB, using hybrid techniques (NL and DGS).

In addition, a study by Ou, Cai and Qian [25], a new MIMO antenna design was proposed by implementing an NL between two coupled dual-band antennas, and was based on highly spaced antennas with phase change element design principle. The antenna used a C-shape structure on the radiator. The designed NL produced a reverse coupling to create an imaginary admittance number. Hence, the NL eliminates the unwanted coupling at the port 1 when port 2 was excited. Each antenna port added a matching inductor-capacitor (LC) network to give higher isolation.

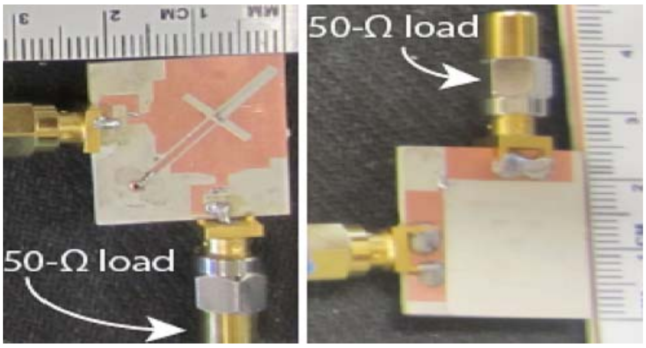


Fig.8: MIMO Antenna with a single shared radiating element [23]

Goraia, A., Dasgupta D. and Ghatak R. [26] designed a MIMO system of 30 × 41 mm based on a Hilbert slot unit monopole antenna results with a bandwidth of 8.5 GHz with the mutual coupling is under 20 dB, envelope correlation coefficient less than 0.1, and efficiency less than 80%, as shown in fig.9. The MIMO antenna was proposed using hybrid techniques (neutralization line and defected ground structure).

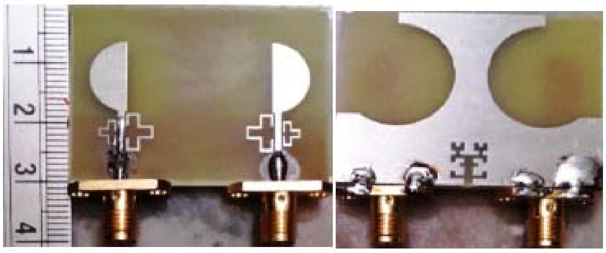


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Fig.9: Configuration of the Hilbert Fractal Slot MIMO Antenna [26]

Jeet B., Abhik G., and Rowdra G. [27] designed a MIMO system of 30.75 × 37.8 mm based on a Hilbert slot unit monopole antenna results with a bandwidth of 8.5GHz with the mutual coupling is under 20 dB, envelope correlation coefficient less than 0.035, and efficiency (52 - 72) %, using hybrid techniques (NLs and DGS), as shown in Fig.10.

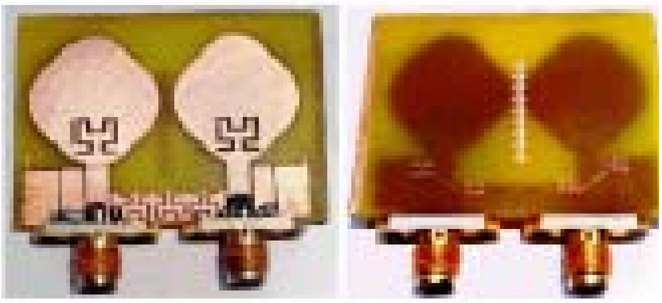

Fig.10: A Prototype of Fractal MIMO Antenna [27]

All research previously mentioned in the literature review is aimed to design MIMO antenna with compact size, lower envelope correlation coefficient and good isolation, table 2 shows the number of designs recently published for the MIMO antenna.

Table 2: The fractal-shaped microstrip antenna

Ref.	Area (mm3)	ECC	Isolation
[2]	21 × 24 × 0.8	0.05	21
[28]	18 × 22.8 × 0.8	-	15
[29]	62 × 38 × 1.6	-	19.3
[30]	150 × 100 × 0.8	0.003	20
[31]	30 × 24 × 1.6	0.1	12
[32]	26 × 26 × 0.762	0.1	19
[33]	150 × 200 × 0.8	0.005	14
[34]	40 × 100 × 0.76	0.1,	10
[35]	54 ×33 ×0.8	-	15
[36]	42×34×1	0.35	20
[37]	100 × 36 × 0.78	-	40
[38]	30 × 60 × 1.6	0.002	20
[39]	45 × 60 × 0.8	0.5	30
[40]	40 × 26 × 1.6	0.012	17.5
[41]	48 × 48.32 × 1.3	0.001	26.5
[42]	65 × 35 × 0.82	0.003	12
[43]	24 × 25 × 0.82	0.02	15
[44]	40 × 40 × 1.6	-	14
[45]	40 × 80 × 1.6	-	23
[46]	40 × 80 × 0.8	-	17.4
[47]	40 × 40 × 2	0.15	27
[48]	56 × 38 × 2.25	0.0004	24
[49]	137×77×3.048	-	18
[50]	42 × 42 × 1.6	-	23
[51]	100 × 80 × 4.5	17.4	17.4
[52]	139.3×66×1.6	0.15	27
[53]	58 × 44 × 1.6	0.0004	24
[54]	60 × 32 × 9	-	18
[55]	60 × 30 × 0.8	-	23
[56]	37 × 56 × 1.6	0.08	15
[57]	24 × 49 × 0.8	0.03	12.5
[58]	150×200×1.6	0.1	10
[59]	50 × 70 × 1.6	-	20
[60]	42 × 39.7 × 1.6	-	15
[61]	45 × 80 × 1.57	0.062	15
[62]	30.75×29.4×1.6	0.5	20
[63]	80 × 100 × 0.8	-	16.5
[64]	120 × 60× 0.8	-	20
[65]	50 × 50 × 3.17	-	24
[66]	50 × 25 × 1.6	0.3	15
[67]	68 × 31 × 1.6	0.0.4	20
[68]	50 × 25 × 1.6	0.3	22
[69]	36 × 22 × 1.6	0.25	20
[70]	54 × 23 × 1.6	0.0006	20
[71]	52 .8× 32.4 × 0.03	0.0004	42
[72]	47.22 × 35.33 × 1.57	0.005	20
[73]	120 × 60 × 1.52	0.0056	12
[74]	26 × 46 × 0.8	0.002	21.5
[75]	21 × 24 × 0.8	0.05	18.5
[76]	21 × 24 × 0.8	0.0	21
[77]	24 × 21 × 0.8	0.002	18.5
[78]	31 × 31 × 0.8	0.0008	29
[79]	20 × 25 × 0.8	0.026	22
[80]	12.5 × 37 × 0.8	0.009	16
[81]	12.5 × 37 × 0.8	0.002	34

Conclusion

This paper presents a survey of isolation techniques to reduce mutual coupling, with the key focus on some important design parameters such as isolation, ECC, and size. Further, different MIMO antenna designs and isolation techniques are also presented. Different isolation methods for MIMO antennas, that have been reported in the recent literature, are also reported.

Authors: Anwer Jabbar Hasan Al-saedi, *Email:* 100415316@alumnos.uc3m.es*; Jesus Carretero Perez, Email:* jesus.carretero@uc3m.es.

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