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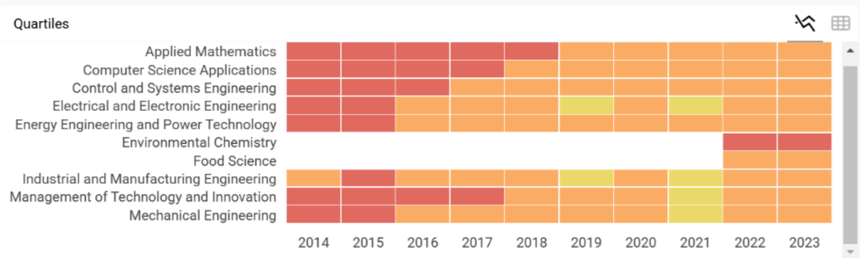

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About the Journal

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WIDE BAND AND HIGH GAIN MICROSTRIP ANTENNA USING PLANAR SERIES ARRAY 4×2 ELEMENT FOR 5G COMMUNICATION SYSTEM

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The 5G communication system requires an antenna as a receiving device that has high performance including wide bandwidth and high gain. Microstrip antennas have advantages such as low cost, suitable for high frequencies and easy to integrate with other devices. One of the disadvantages of microstrip antennas is their narrow bandwidth and low gain. Therefore, microstrip antennas with wide bandwidth and high gain are especially needed to support 5G communication systems. This paper provides a solution by proposed a wide bandwidth and high gain microstrip antenna operating at a resonant frequency of 3.5 GHz for a 5G communication system. The proposed antenna was developed in four stages starting from a single element, a two-element series array, a 4-element series array and a 4×2-element planar series array. A series planar array technique is proposed to increase the gain and bandwidth of the microstrip antenna simultaneously. In this paper, simulations and measurements from the proposed antenna are displayed and compared comprehensively to show the performance improvement from each stage of the development of the proposed model. Based on the measurement results, the designed antenna has an impedance bandwidth (IBW) of 0.6 GHz and fractional bandwidth (FBW) of 17.14 % with a frequency range of 3.11–3.71 GHz and maximum gain of 12.2 dB at a resonant frequency of 3.5 GHz. The bandwidth and gain of the antennas increased by 205 % and 99.03 % compared to single element antennas, respectively. Therefore, the proposed antenna can be recommended to be used as a receiving antenna for 5G communication systems

Keywords: antenna, microstrip, planar, series, array, bandwidth, gain, 5G, communication system, high frequencies

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1. Introduction

The 5G communication system offers high data rates and low latency, so it requires wide bandwidth [1]. Based on [2], the resonant frequency of the 5G communication system is divided into three classifications: high band, middle band and low band. One of the recommended frequencies for 5G communication systems is 3.5 GHz which is included in the middle band category [3]. Furthermore, to support the communication system between transmitter and receiver, antennas with high performance are needed. The key parameters to show the performance of the antenna are reflection coefficient, bandwidth, gain and radiation pattern [4]. One of the antennas that has been developed for wireless communication systems is the microstrip antenna because it has the advantages of compact dimensions, low cost and has the ability to operate at high frequencies [5, 6]. However, microstrip antennas have limitations including narrow bandwidth, low gain, and low directivity [7]. Furthermore, to support the communication system between transmitter and receiver, antennas with high performance are needed. The key parameters to show the performance of the antenna are reflection coefficient, bandwidth, gain and radiation pattern [8]. Therefore, antennas with wide bandwidth and high gain are needed to support wireless communication systems such as Wi-Fi, 4G and 5G.

2. Literature review and problem statement

One of the antennas that has been developed for wireless communication systems is the microstrip antenna because it has the advantages of compact dimensions, low cost and has the ability to operate at high frequencies [9, 10]. However, microstrip antennas have limitations including narrow bandwidth, low gain and directivity [11]. Several previous studies have described and proposed microstrip antennas for 5G communication systems using several techniques including fractal, array and parasitic [12–14]. Previous studies presented by [15] have described microstrip antennas with wide bandwidth by adding parasitic elements that are placed above to the radiating elements. However, the gain of the antenna is still low, so it needs to be increased. Another study by [16] proposed a microstrip antenna configured in an array with four elements operating at a resonant frequency of 3.5 GHz with a bandwidth of 0.7 GHz and a gain of 9.24 dB. However, the increase in bandwidth is not in line with the gain so that when the bandwidth increases, the gain will decrease.

Therefore, a method and stages of development are needed to produce an antenna that has wide bandwidth and high gain simultaneously. Therefore, new methods and model development are needed to produce antennas that have wide bandwidth and high gain simultaneously. Generally, the addition of elements from antennas with a parallel configuration will increase the gain, but on the other hand the bandwidth becomes narrower. This is due to the mutual inductance between the elements of the antenna. For this reason, series arrays can be used as a solution to reduce mutual inductance between elements so that the gain and bandwidth can increase simultaneously.

3. The aim and objectives of the study

The aim of the study is to produce a compact microstrip antenna for 5G communication system.

To achieve this aim, the following objectives are accomplished:

– to simulation of characteristics of the antenna;

– to enhance bandwidth of microstrip antenna ≥200 MHz;

– to enhance gain of microstrip antenna ≥10 dB.

4. Materials and methods

4. 1. Development model of proposed antenna

In this paper, the proposed antenna is developed based on four stages starting from a single element, a series array with 2 elements, a series array with 4 elements and the final stage is a series planar array with 4×2 elements. The model and development stages of the proposed antenna are shown in Fig. 1.

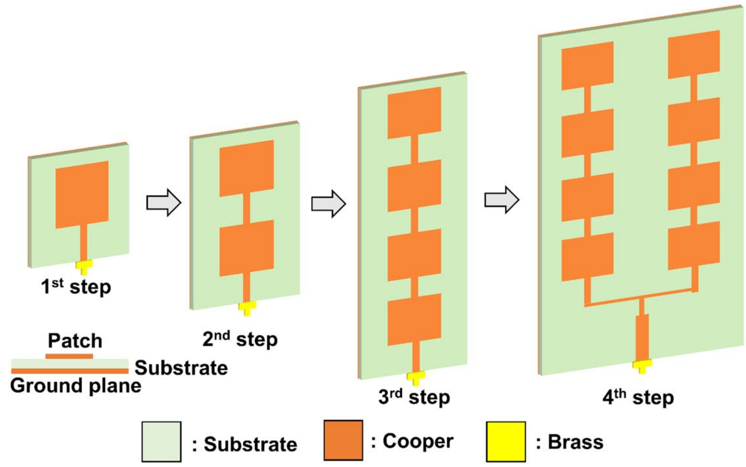


Fig. 1. Development model of proposed antenna

Fig. 1 shows a single element microstrip antenna with a rectangular shape where the patch antenna is on the top layer of the substrate which functions as a radiating element while the bottom layer functions as a ground plane as 1st step. The substrate used was FR-4 with a dielectric constant of 4.3, a loss tan of 0.0265 and a thickness of 1.6 mm. The proposed antenna is connected directly with the RP-SMA connector with an impedance of 50 Ω. In the 2nd and 3rd step, single element antennas are configured in series arrays with two and four elements. It should be noted, the dimensions of the patch antennas are identical whereas the microstrip lines are used to control the impedance and reflection coefficient of the proposed antenna. Furthermore, the 4th step model shows that the antenna is developed with a series planar array with 4×2 elements. It should be noted, the distance between radiating elements in a series planar array structure will greatly affect the bandwidth and gain of the antenna.

4. 2. Design of single element microstrip antenna

Basically, the dimensions of a microstrip antenna are greatly influenced by the type of substrate and the resonant frequency used. In this paper, microstrip antennas are developed based on a rectangular shape where the length of the patch is represented as L while the width is represented as W. Furthermore, the dimensions of W and L can be determined based on following equation as follows:

$$W=\frac{c}{2f_o\sqrt{\frac{\varepsilon_r}{2}}}, \quad (1)$$

$$L=L_{eff}-\Delta_L, \quad (2)$$

$$L_{eff}=\frac{c}{2f_o\sqrt{\varepsilon_{eff}}}, \quad (3)$$

$$\varepsilon_{eff}=\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}}, \quad (4)$$

$$\Delta_L=0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}, \quad (5)$$

where W and L represent the length and width of the patch, f_o represents the resonance frequency, ε_r represents the permittivity of the substrate, ε_{eff} represents the effective permittivity of the substrate at a certain resonance frequency, h represents the thickness of the substrate while Δ_L represents the edge effect of the fringing field of the patch.

Furthermore, microstrip lines are proposed to control the impedance and reflection coefficient of the antenna. The dimensions of the microstrip line are greatly influenced by the input impedance and the resonant frequency used. In this paper, the input impedance used is 50 ohms. The dimensions of the microstrip line can be determined using the following equation:

$$W_z = \frac{2h}{\pi}\left\{ \begin{matrix} B-1-\ln(2B-1)+ \\ +\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right] \end{matrix} \right\}, \quad (6)$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}, \quad (7)$$

where W_z is the width of the microstrip line, Z_o is the impedance of the antenna and B is the impedance constant. The impedance of the antenna is 50 Ω in line with the impedance of the connector used. Furthermore, the length of the microstrip line (L_z) is ¼ lambda (λ_g) which is determined by the following equation:

$$L_z = \frac{1}{4}\lambda_g, \quad (8)$$

$$\lambda_g = \frac{\lambda}{\varepsilon_{eff}}. \quad (9)$$

The structure and design of the single element microstrip antenna with a rectangular shape is shown in Fig. 2.

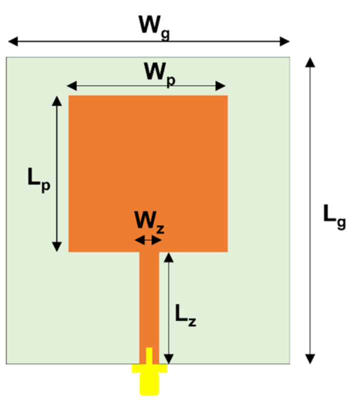


Fig. 2. Design of single element microstrip antenna

Fig. 2 describes the structure of a single element microstrip antenna where the antenna is connected to the connector using a transmission line with an impedance of 50 Ohms. The dimensions of the antenna are obtained using equations (1) to equations (5) while the dimensions of the transmission line are obtained using equations (6) and equations (7). Moreover, the overall dimensions of the single element microstrip antenna are shown in Table 1.

Table 1

Dimension of single element microstrip antenna

Parameter	Dimension (mm)
W_g	40
L_g	40
W_z	3
L_z	12.7
W_p	25
L_p	20

The antenna is designed and simulated using electromagnetic (EM) simulation with the Finite element method (FEM) based on HFSS 15.0. Parameters observed were reflection coefficient, VSWR and gain of the designed antenna. The simulation results of a single element microstrip antenna are shown in Fig. 3.

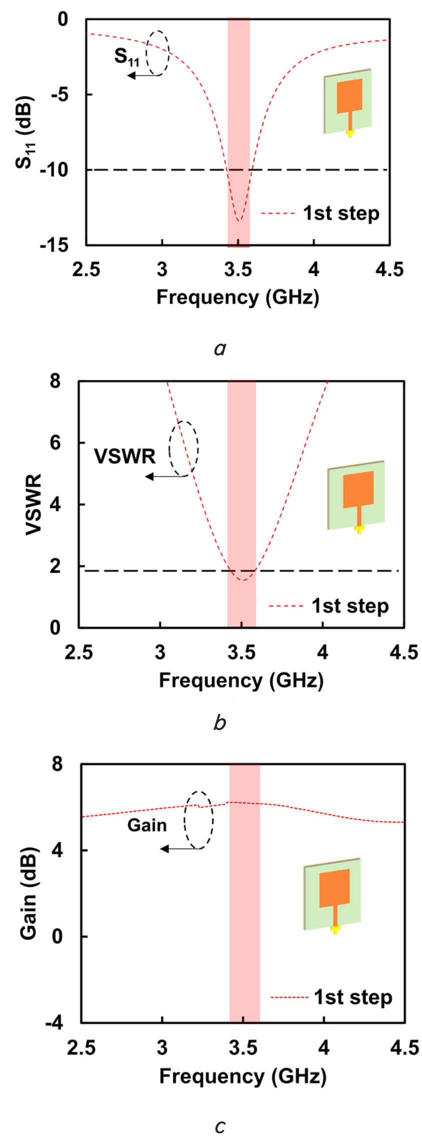


Fig. 3. Simulation result of single element microstrip antenna: *a* – S_{11}; *b* – VSWR; *c* – Gain

Fig. 3, *a* shows that the single element microstrip antenna has been operating at a resonant frequency of 3.5 GHz with a reflection coefficient (S_{11}) –13.39 dB. Moreover, the proposed antenna has VSWR of 1.54 and a gain of 6.2 dB as shown in Fig. 3, *b*, *c*. Furthermore, the impedance bandwidth (IBW) of the single element microstrip antenna is 0.2 GHz with a frequency range of 3.42–3.62 GHz. These findings indicate that the bandwidth obtained is narrow, so it needs further optimization.

4. 3. Design of series array microstrip antenna with two and four elements

At this stage, the antenna is developed using a series array configuration with two elements. The dimensions of the patch and transmission line antennas are identical for a single element. The target of adding a patch in a series array configuration is to increase the gain of the antenna. Fig. 4 shows the design of a microstrip antenna with a series array configuration with two elements.

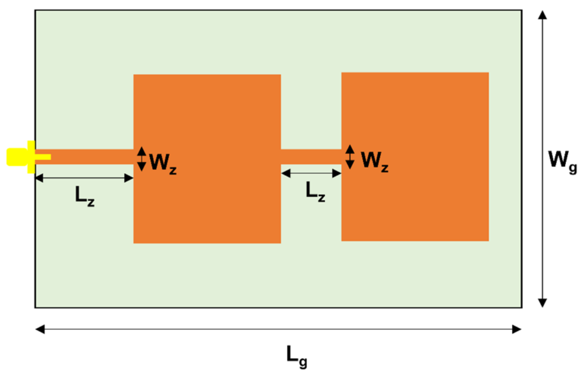


Fig. 4. Design of series array microstrip antenna with two elements

Fig. 4 shows that the two patch antennas are connected using a transmission line with L_z=12.7 mm in series and arranged in a vertical configuration. The dimensions of W_g and L_g are 40 mm and 75 mm, respectively. Furthermore, the simulation results of a microstrip antenna configured in series array with two elements are shown in Fig. 5.

Fig. 5, *c* shows that the implementation of a series array with two elements produces a high gain antenna characteristic with a gain of 8.37 dB at a resonant frequency of 3.5 GHz. However, the impedance bandwidth of the antenna is still narrow where the antenna operates at two different resonance frequencies of 3.15 GHz and 3.61 GHz with S_{11}≤–10 dB and VSWR≤2 as shown in Fig. 5, *a*, *b*. Therefore, it is necessary to do further optimization so that the bandwidth of the antenna increases. It should be noted, the impedance bandwidth is observed from S_{11}≤–10 dB and VSWR≤2. Furthermore, the proposed antenna is optimized using a series array with four elements as shown in Fig. 6 with W_g of 42 mm and L_g of 142 mm, while the simulation results are shown in Fig. 7.

Fig. 7, *a*, *b* shows that the impedance bandwidth of the antenna increases after being configured using a series array with 4 elements. The proposed antenna has an impedance bandwidth of 0.44 GHz with a frequency range of 3.11–3.55 GHz. In addition, the gain of the antenna also increases to 9.09 dB at a resonant frequency of 3.5 GHz as shown in Fig. 7, *c*. These findings indicate that the addition of the number of elements greatly affects the bandwidth and gain of the antenna. Furthermore, the bandwidth and gain of the antenna will be optimized using a series planar array configuration with 4x2 elements.

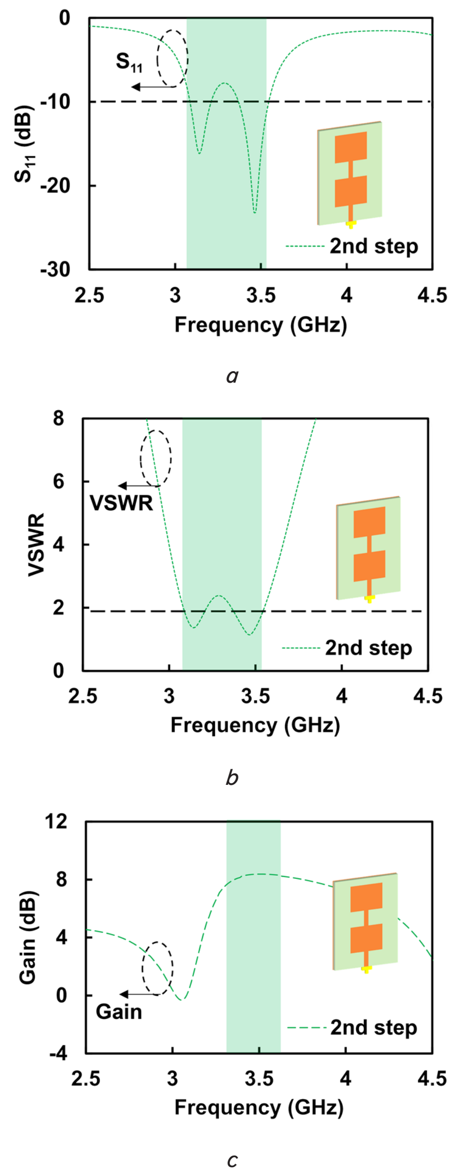


Fig. 5. Simulation result series array microstrip antenna with two elements: *a* – S_{11}; *b* – VSWR; *c* – Gain

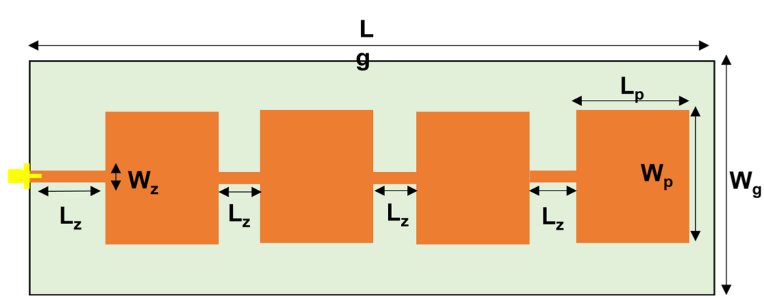
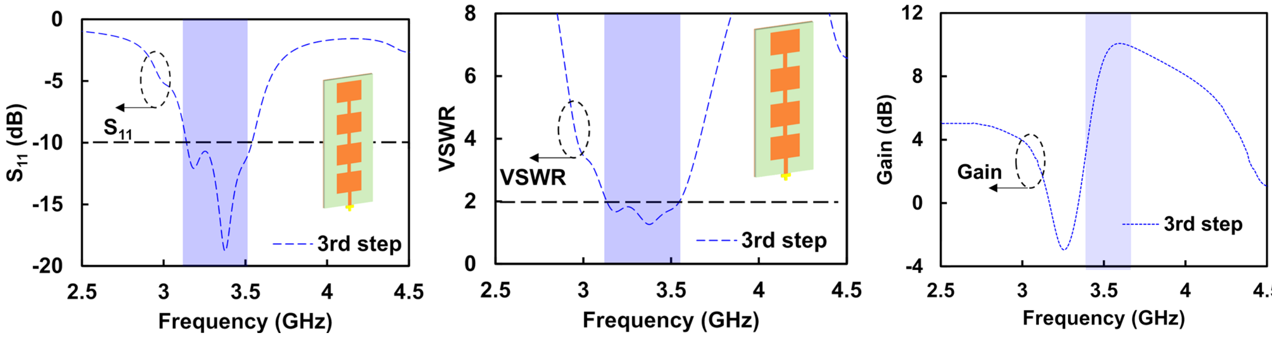


Fig. 6. Design of series array microstrip antenna with four elements



a *b* *c*

Fig. 7. Simulation result series array microstrip antenna with four elements: *a* – S_{11} ; *b* – VSWR ; *c* – Gain

4. 4. Design of planar series array microstrip antenna with 4x2 elements

At this stage, the antenna with the series array is configured as a vertical planar separated by a distance represented by d_a. The distance between elements (d_a) is determined by the following equation:

$$d_a = \frac{1}{4}\lambda, \quad (9)$$

$$\lambda = \frac{c}{f}, \quad (10)$$

where d_a represents the gap between the elements of the array, λ represents the electrical length of the antenna and *c* is the speed of light (3×10^8 m/s). The design and model of the series planar array antenna with 4×2 elements is shown in Fig. 8.

Fig. 8 shows that the series array configuration antenna with four elements each connected planar using a transmission line with a step impedance of 50 Ohm (Z_0), 70.7 Ohm (Z_s) and 100 ohm (Z_L) which functions as impedance matching to control the reflection coefficient and VSWR of antenna. The width of the transmission line determines its impedance while the impedance of the transmission line can be determined based on the following equation:

$$Z_s = \sqrt{Z_0 . Z_L}. \quad (11)$$

Furthermore, the overall dimensions of the series planar array antenna with 4×2 elements are shown in Table 2.

The overall simulation results of a series planar array antenna with 4×2 elements are shown in Fig. 9.

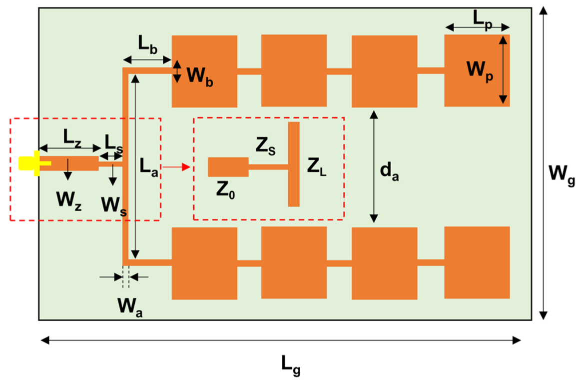
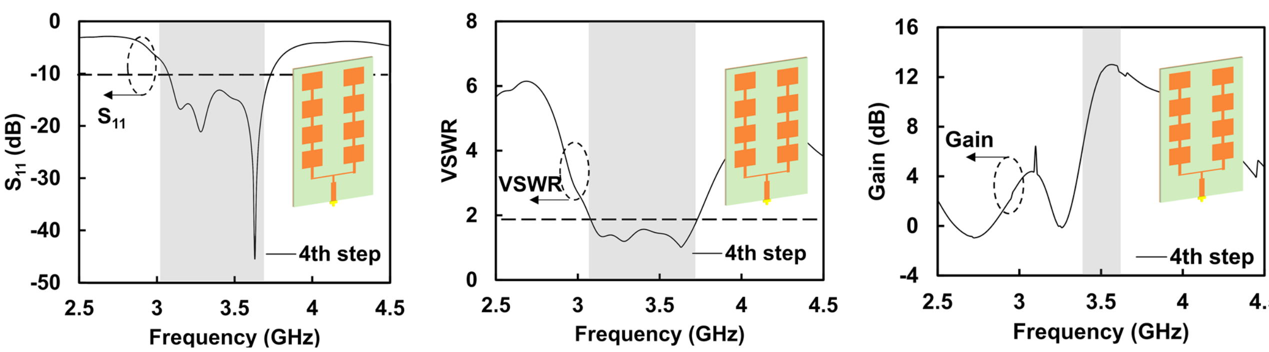


Fig. 8. Design of series planar array microstrip antenna with 4x2 element

Table 2

Dimension of series planar array antenna with 4×2 elements

Parameter	Dimension (mm)
W_g	130
L_g	187
W_z	3
L_z	40
W_p	25
L_p	20
W_s	1
L_s	3
W_a	2
L_a	94
W_b	3
L_b	12.7



a *b* *c*

Fig. 9. Simulation result of series planar array microstrip antenna with 4×2 elements: *a* – S_{11}; *b* – VSWR; *c* – Gain

Fig. 9 shows the bandwidth and gain of the antenna significantly increased after being configured with a series planar array with 4×2 elements. The impedance bandwidth of the antenna is 0.61 GHz with a frequency range of 3.1–3.71 GHz as shown in Fig. 9, *a*, *b* while the gain increases to 12.34 dB at a resonant frequency of 3.5 GHz as shown in Fig. 9, *c*. These findings indicate that the performance of the antenna increases significantly after being developed with a series planar array configuration with 4×2 elements.

5. Results of development compact microstrip antenna for 5G communication system

5. 1. Simulation of characteristics of the antenna

The model development of the proposed antenna has been described and simulated in the previous section. Furthermore, the performance of the antenna development is observed by comparing the impedance bandwidth and gain. A comparison of the simulation results for each stage is shown in Fig. 10.

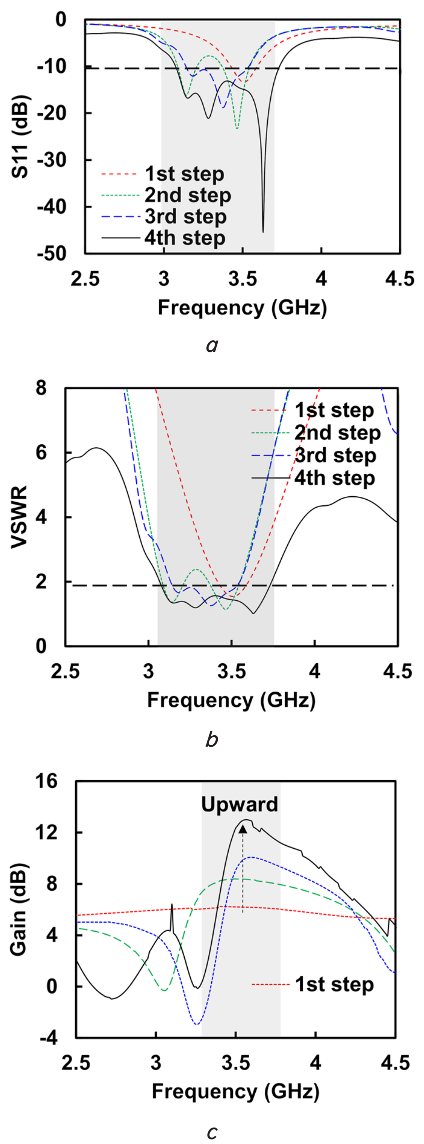


Fig. 10. Comparison of simulation result from development model of proposed microstrip antenna: *a* – S_{11}; *b* – VSWR; *c* – Gain

Fig. 10, *a*, *b* show that the bandwidth impedance of the antenna increases significantly after being configured with a series planar array. At the 1st step, the bandwidth of the antenna is 0.2 GHz which increases to 0.44 GHz and 0.62 GHz at the 3rd and 4th steps, respectively. Furthermore, the gain of the antenna at the resonant frequency of 3.5 GHz also increases gradually where the 1st step gain is 6.2 dB, the 2nd step is 8.37 dB while the 3rd step and 4th step are 9.09 dB and 12.34 dB, respectively. In other words, the bandwidth and gain of the proposed antenna increase by 205 % and 99.03 % compared to the single-element microstrip antenna. These findings indicate that the gain and bandwidth of the proposed antenna increase simultaneously.

Based on Fig. 10, *a*, *b*, the bandwidth performance of the antenna at the 1st step, 2nd step, 3rd step and 4th step are shown in Table 3.

Table 3

Bandwidth of proposed antenna based on development model

Step	Range of frequency (GHz)	Bandwidth (GHz
1st step	3.42–3.62	0.20
2nd step	3.38–3.54	0.16
3rd step	3.11–3.55	0.44
4th step	3.10–3.70	0.60

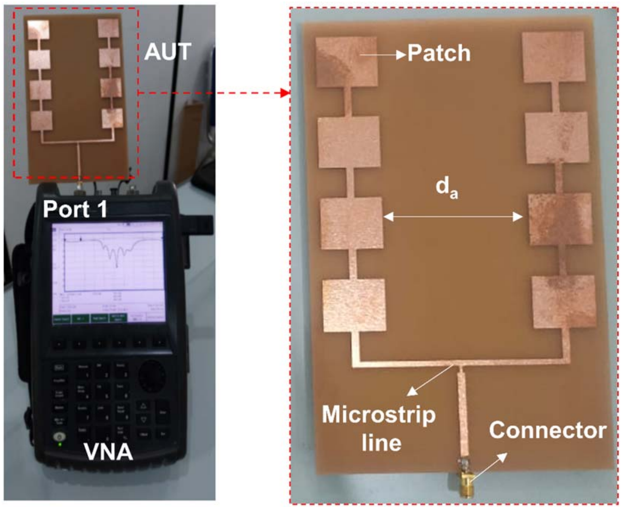
Based on Table 3, the bandwidth of the antenna increases at the 3rd and 4th step. However, at the 2nd step, the bandwidth of the antenna is narrower and has dual band characteristics as shown in Fig. 5, *a*, *b*. Furthermore, the performance comparison of the proposed antenna is determined based on the following equation:

$$BW = \frac{(Optimized\ BW - Initial\ BW)}{Initial\ BW} \times 100\ \%. \quad (12)$$

5. 2. Bandwidth performance of proposed antenna

Furthermore, the antenna was fabricated using FR-4 substrate with a dielectric constant (ε_r) of 4.3, a loss tan (tan δ) of 0.0265 and a thickness (*h*) of 1.6 mm. The proposed antenna is connected to the RP-SMA connector with an impedance of 50 Ω as shown in Fig. 11, *b*. The measurement setup of the antenna is shown in Fig. 11, *a* where the proposed antenna is connected to port 1 of the Vector Network Analyzer (VNA). The frequency range used in the measurement process is 2.5–4.5 GHz with a sweep frequency of 0.01 GHz and an ambient temperature of 25 °C. Moreover, the simulation and measurement results are comprehensively compared to observe the performance of the fabricated antenna. Comparison results of the simulation and measurement processes of the proposed antenna are shown in Fig. 12.

Fig. 12 shows that the fabricated antenna has performance and characteristics that are in line with the simulation process. The impedance bandwidth (IBW) of the antenna with $S_{11} \leq -10$ dB and VSWR≤2 from the measurement process is 0.6 GHz with a frequency range of 3.11–3.71 GHz. The proposed antenna has wide bandwidth characteristics and meets the criteria and specifications for a 5G communication system where the required bandwidth is 200 MHz.



a *b*

Fig. 11. Measurement process of proposed antenna: *a* – measurement setup for near-field parameter; *b* – fabrication of proposed antenna

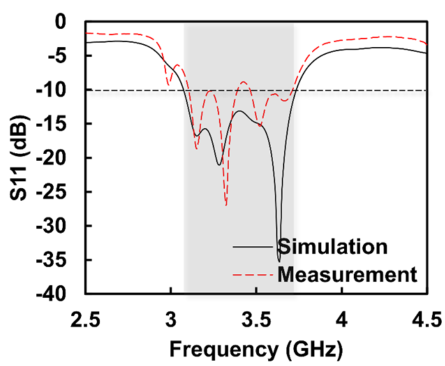


Fig. 12. Comparison between simulation and measurement of reflection coefficient of proposed antenna

The bandwidth of the single element antenna represents the initial bandwidth while the optimization bandwidth is obtained from the 2nd, 3rd and 4th steps. Based on equation (12), the bandwidth of the single element antenna increases 102 % and 205 % at the 3rd and 4th steps respectively. Furthermore, the performance is also observed in terms of increasing the gain of the antenna. Based on Fig. 10, *c*, the gain performance of the antenna at the 1st step, 2nd step, 3rd step and 4th step is shown in Table 3.

Table 4

Gain of proposed antenna based on development model

Step	Resonant frequency (GHz)	Gain (dB)
1st step	3.5	6.20
2nd step	3.5	8.20
3rd step	3.5	9.09
4th step	3.5	12.34

Based on Table 4, the gain of the proposed antenna increases gradually from the 1st, 2nd, 3rd and 4th steps in line with the increase in the number of elements of the antenna. Furthermore, the performance comparison of the proposed antenna is determined based on the following equation:

$$BW = \frac{(Optimized\ Gain - Initial\ Gain)}{Initial\ BW} \times 100\ \%. \qquad (13)$$

5. 3. The gain of microstrip antenna

Furthermore, the gain and radiation pattern of the proposed antenna are observed by measuring in the anechoic chamber as shown in Fig. 13 where the designed antenna is positioned as a receiver (*Rx*) and a comparison antenna is used as a transmitter (*Tx*) separated by a distance *d*=60 cm and connected to port 1 and port 2 of the VNA using a coaxial cable.

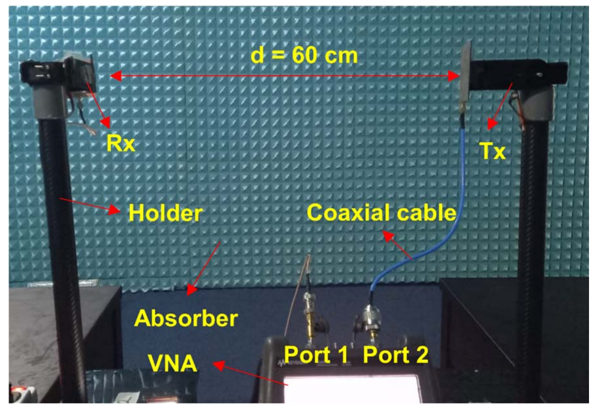
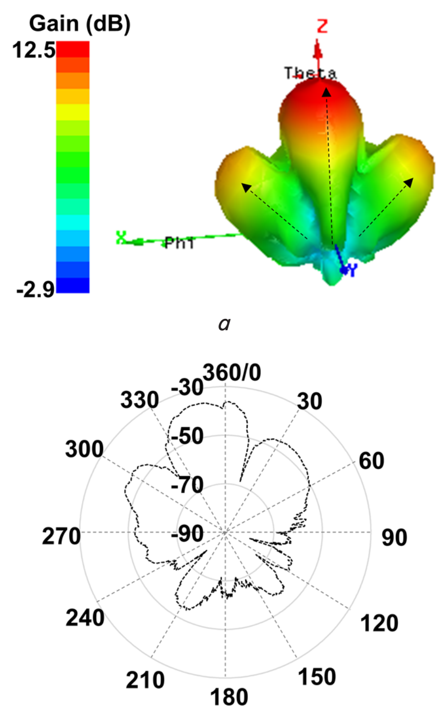


Fig. 13. Measurement setup for far-field parameter in anechoic chamber

Fig. 14, *a, b* shows the radiation pattern from the measurement results in line with the simulation results with a resonant frequency of 3.5 GHz with gain of 12.5 dB. These findings confirm that the proposed antenna has a high gain ≥10 dB with a directional radiation pattern at a resonant frequency of 3.5 GHz.



a

b

Fig. 14. Far field of proposed antenna: *a* – simulation result; *b* – measurement result

6. Discussion of experimental result of proposed antenna

The gain of the single element antenna represents the initial gain while the optimization gain is obtained from the 2^{nd}, 3^{rd} and 4^{th} steps. Based on equation (13), the bandwidth of the single element antenna increases 32.25 %, 45.48 % and 99.03 % at the 2^{nd}, 3^{rd} and 4^{th} steps respectively. In addition, the results presented in Fig. 12, 13 show that the antenna has a bandwidth and gain performance that is in line between the simulation and measurement. This indicates that the antenna has met a predetermined target.

Overall, this paper has comprehensively described and investigated the development of microstrip antennas with wide bandwidth and high gain. The antenna was developed in four steps including single element antenna, series array with two elements, series array with four elements and planar series array with 4x2 elements. The bandwidth and gain of the antenna were successfully increased based on the proposed steps. From the measurement results, the series planar array antenna with 4×2 elements has succeeded in increasing the performance in terms of bandwidth and gain up to 205 % and 99.03 % compared to single element antennas. Moreover, the proposed antenna has a wide bandwidth of 0.6 GHz and a directional radiation pattern with a high gain of 12.34 dB at a resonant frequency of 3.5 GHz. Furthermore, the planar series array method succeeded in increasing the gain and bandwidth simultaneously. The bandwidth of the antenna has met the target ≥200 MHz with a gain ≥10 dB.

However, there are several limitations, including the dimensions of the antenna which are still quite large and only operate at one resonant frequency. Therefore, the future work of this research is to reduce the dimensions of the antenna and optimize the antenna to work at several resonant frequencies so that it can be used for other communication systems such as 4G, Zigbee and Wi-Fi.

7. Conclusions

1. The bandwidth and gain of the proposed antenna is improved simultaneously through four stages including single elements, series arrays with 2×1 elements, series arrays with 4×1 elements and the final stage uses planar series arrays with 4×2 elements.

2. Bandwidth impedance of the proposed antenna is 0.6 GHz and successfully increased up to 205 % compared to single element antenna.

3. Gain of the proposed antenna is 12.5 dB and successfully increased up to 99.03 % compared to single element antenna.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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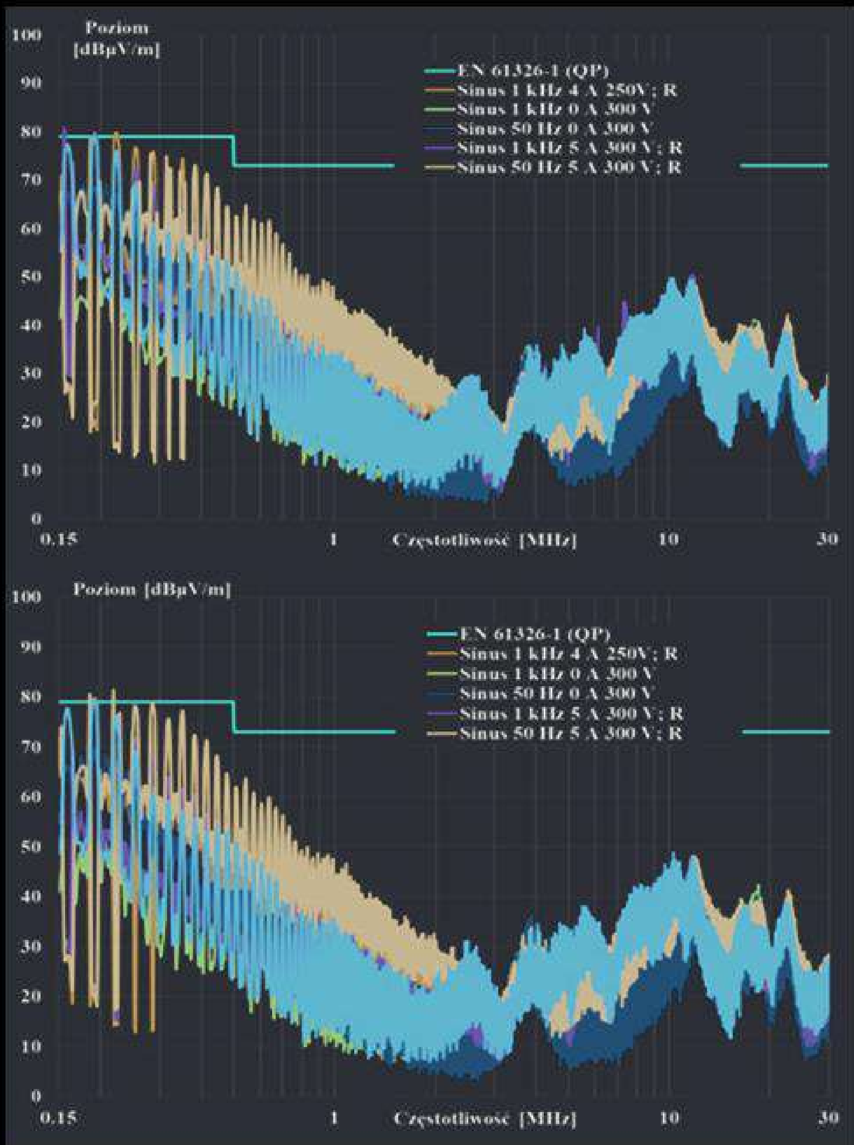

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High Isolation of Dual-Band MIMO Microstrip Antenna with Vertical – Horizontal Configuration for 5G Communication System

***Abstract**. This paper proposes dual-band MIMO microstrip antenna based on circular patch for a 5G communication system. The proposed antenna operates at a resonant frequency of 3.5 GHz and 6 GHz, using a Duroid RO5880 substrate with a dielectric constant of 2.2, a loss tan of 0.0009 and a thickness of 1.57 mm. The dual-band characteristic is obtained by placing a slot in the center of the antenna while an inset feeder is used to control the reflection coefficient. Furthermore, a high isolation coefficient is obtained by controlling the antenna configuration using vertical - horizontal. Based on the simulation results, the proposed antenna produces very good performance with a reflection coefficient of ≤ -10 dB and an isolation coefficient of ≤ -20 dB at the resonant frequency of 3.5 GHz and 6 GHz. This research is a solution for a 5G communication system that requires a dual-frequency receiving antenna that complies with high performance.*

***Streszczenie.** W artykule zaproponowano dwuzakresową antenę mikropaskową MIMO opartą na patchu okrągłym dla systemu komunikacji 5G. Proponowana antena pracuje w częstotliwości rezonansowej 3,5 GHz i 6 GHz, wykorzystując podłoże Duroid RO5880 o stałej dielektrycznej 2,2, współczynniku strat 0,0009 i grubości 1,57 mm. Charakterystykę dwupasmową uzyskuje się poprzez umieszczenie szczeliny w środku anteny, natomiast wbudowany zasilacz służy do kontroli współczynnika odbicia. Ponadto wysoki współczynnik izolacji uzyskuje się poprzez sterowanie konfiguracją anteny w układzie pion - poziom. Na podstawie wyników symulacji proponowana antena charakteryzuje się bardzo dobrymi parametrami użytkowymi przy współczynniku odbicia ≤ -10 dB i współczynniku izolacji ≤ -20 dB przy częstotliwości rezonansowej 3,5 GHz i 6 GHz. Badania te dotyczą rozwiązania dla systemu komunikacji 5G, który wymaga dwuczęstotliwościowej anteny odbiorczej charakteryzującej się wysoką wydajnością. (**Wysoka izolacja dwuzakresowej anteny mikropaskowej MIMO w konfiguracji pionowo-poziomej dla systemu komunikacji 5G**)*

Keywords: 5G, MIMO, dual-band, microstrip antenna, high isolation
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Introduction

The technology of cellular communication has developed and entered the 5th generation (5G) stage, of course it has challenges to achieve high speed, power efficiency and system reliability [1]. Multiple Input Multiple Output (MIMO) is one of the solutions to increase the capacity of the communication system [2]. In addition, spectrum and frequency allocation is very important so that the communication system can run effectively [3]. Based on [4]–[6], one of the recommended frequencies for 5G communication systems is in the range below 6 GHz, including 3.5 GHz and 6 GHz. In addition, high performance antennas are required to be able to transmit information from transmitters and receivers, especially for 5G communication systems. MIMO antenna systems play an important role in wireless communication systems to meet the characteristics of wide bandwidth, higher data rates and limited space. One of the antennas that has been developed for the purposes of wireless communication systems is the microstrip antenna [7].

The development of microstrip antennas for 5G communication systems has been widely described in previous studies [8]–[12]. The previous research presented [13] proposed a Hairpin Filter microstrip antenna that operates for 5G telecommunications systems at a frequency of 4.45 GHz, while the proposed research [14] is a microstrip antenna with a Defected Ground Structure for 5G communications at a frequency of 3.5 GHz. The two previous studies cannot be used for MIMO communication systems because they only consist of one patch. Another study [15] proposed a 4-element MIMO array antenna for 5G communication systems at a resonant frequency of 3.5 GHz, but the isolation coefficient obtained was not optimal. Research [16] proposes MIMO antennas for 5G communication systems that are already dual-band at frequencies of 0.7 GHz and 2.3 GHz and have good isolation coefficient. However, the proposed resonant frequency does not meet the criteria and requirements of the 5G communication system regulations in Indonesia, where the recommended resonant frequencies are 3.5 GHz and 6 GHz.

Therefore, this study provides a solution by proposing a MIMO microstrip antenna which has dual-band characteristics and high isolation. The proposed antenna has a circular patch operating at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz with a reflection coefficient (S_{11}) ≤ -10 dB and mutual coupling (S_{21}) ≤ -20 dB. In order to achieve dualband characteristics, the slot and inset method is proposed to control the parameter S_{11} and the resonant frequency of the antenna. Furthermore, a high isolation coefficient is obtained by controlling the antenna configuration. The main objective of this research is to produce a MIMO microstrip antenna with dual-band characteristics and high isolation value so that it can be recommended as a receiving antenna for 5G communication systems.

Antenna Design

In this paper, the proposed antenna is designed using a Duroid RO5880 substrate with a dielectric constant of 2.2, a loss tan of 0.0009 and a thickness of 1.57 mm. The antenna structure consists of a radiating element made of copper and a connector made of brass. The model development of the proposed antenna is shown in **Fig. 1**.

The first stage of this research is to design a single-element antenna based on a circular patch connected to a connector with an impedance of 50 Ohm using a microstrip channel as shown in Fig. 1 (a). The second stage is optimizing the antenna by adding an inset on the edge of the feeder and a slot in the center of the patch antenna which serves to reduce the reflection coefficient and generate dual frequencies as shown in Fig.1 (b). In this paper, the antenna is designed to operate at dual frequencies at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz for 5G communication system. The third stage is to develop the proposed antenna model with 2 MIMO ports arranged vertically and separated by a distance (d) as shown in **Fig.1 (c)**. It should be noted, the distance between the two MIMO antennas will affect the isolation coefficient (S_{21}). The final stage of antenna design is to optimize the MIMO antenna structure by rotating one of the antenna patches to be horizontal as shown in Fig. 1 **(d)**. This aims to reduce S_{21} so that the antenna has a high mutual coupling.

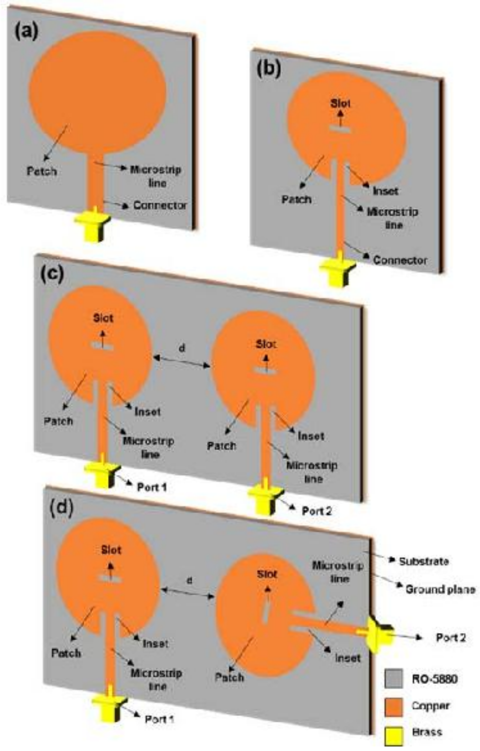

Fig. 1 Model development of the antenna; (a) single element circular patch antenna design, (b) circular patch antenna design with inset and slot, (c) 2 port MIMO antenna design with vertical configuration, (d) 2 port MIMO antenna design with vertical-horizontal configuration

The dimensions of the circular patch antenna are obtained using equations (1) and (2) where the logarithmic function will affect the dimensions of the circular patch antenna [8].

(1) $$F = \frac{8{,}791\,x10^{9}}{fr\sqrt{\varepsilon r}}$$

where *F* represents the logarithmic function, f_r represents the resonant frequency and ε_r represents the dielectric constant. Furthermore, the radius of the circular patch microstrip antenna is determined based on equation (2).

(2) $$r = a\sqrt{1} + \frac{2\,h}{\pi\,F\,\varepsilon\,r}\left[Ln\left(\frac{\pi\,F}{2\,h}\right)\right] + 1{,}7726$$

where *r* represents the radius of the circular patch antenna, *h* is the thickness of the substrate, *π* is 3,14. Furthermore, the dimensions of the width of the microstrip feed line (W_z) with an impedance value of 50 Ω are determined using equation (3) and equation (4) [17].

(3) $$B = \frac{60\,\pi^2}{Zo\sqrt{\varepsilon_{reff}}}$$

(4) $$Wz = \frac{2\,h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon r}{2\varepsilon r}\left[\ln(B-1) + 0{,}39 - \frac{0.61}{\varepsilon r}\right]\right\}$$

where *B* represents the impedance constant of the microstrip line, Z_0 is the impedance of the microstrip line, ε_{reff} is the effective dielectric constant of the microstrip line and W_z represents the width of microstrip lines. The overall dimensions of the circular patch microstrip antenna are shown in Table 1.

Table **1**. Dimension of circular patch microstrip antenna

Parameter	Dimension (mm)
r	16
W_z	2,2
L_z	17
W_g	50
L_g	50

Furthermore, the ground planes used in this paper are represented as W_g and L_g with dimensions of 50 mm x 50 mm. The circular patch microstrip antenna design is shown in Fig. 2.

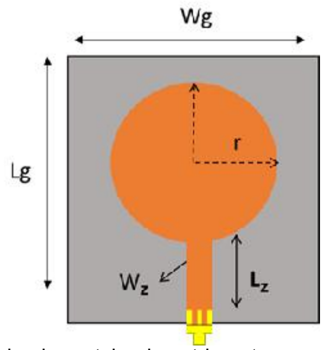

Fig. 2 Design of a circular patch microstrip antenna

The simulation and design of the proposed antenna was carried out using AWR MWO 2009 software by observing S_{11}, VSWR and gain of proposed antenna. The simulation results of the single element circular patch antenna are shown in Fig. 3(a), Fig. 3(b) and Fig. 3(c).

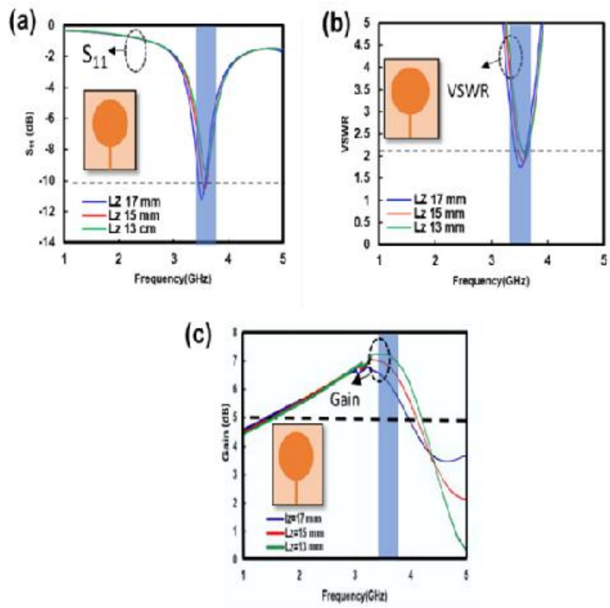

Fig. 3 Simulation results of circular microstrip patch antenna; (a) S_{11} of proposed antenna (b) VSWR of proposed antenna, (d) gain of proposed antenna

Table 2. Simulation result from iteration of L_z

Iteration	L_z (mm)	Parameters			
		S_{11} (dB)	VSWR	BW (MHz)	*Gain* (dB)
1[st] iteration	13	-8,73	2,37	70	7,2
2[nd] iteration	15	-10,03	2,05	80	6,8
3[rd] iteration	17	-11,21	1,77	120	6,3

Fig. 3 (a), Fig. 3 (b) and Fig. 3 (c) show that the parameters S_{11}, VSWR and gain of the single element circular patch antenna can be controlled by changing the dimensions of L_z with a range of 13 mm – 17 mm as shown in Table 2.

Table 2 shows the best performance of the proposed antenna obtained at 3rd iteration where the antenna operates at a resonant frequency of 3.5 GHz with S_{11} of -11.21 dB, VSWR of 1.77, bandwidth of 120 MHz and gain of 6.3 dB. From the simulation results it can be seen that the antenna still works at one resonant frequency and has S_{11} and VSWR which are still not optimal, so it needs to be optimized.

In this paper, dual-band frequencies are generated using the slot technique while the reduction of the reflection coefficient of each resonant frequency is controlled using an inset feed. Furthermore, the design of single element circular patch antenna with inset and slot is shown in **Fig. 4**.

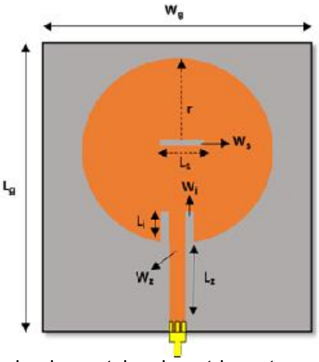

Fig. 4. Design of circular patch microstrip antenna with inset and slot

The simulation results of the circular patch antenna with inset and slot are shown in Fig. 5 (a) and Fig.5 (b) where the dimensions of the inset represented by L_i and the slot are L_s.

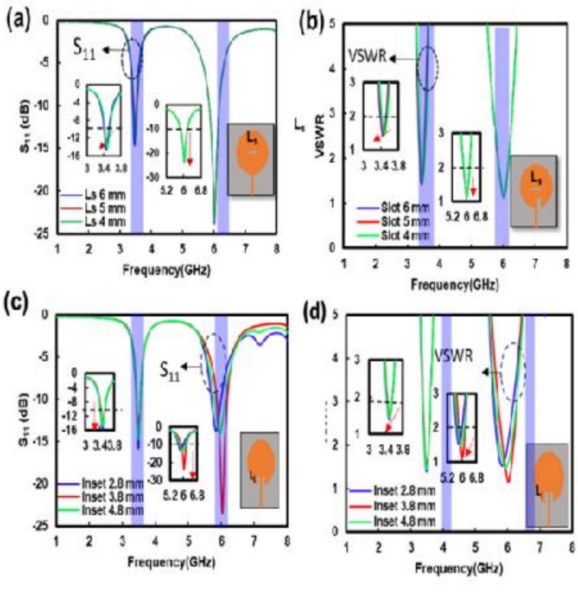

Fig. 5 Design simulation results of circular patch antenna with inset and slot (a) S_{11} circular patch antenna with slot, (b) VSWR circular patch antenna with slot, (c) S_{11} circular patch antenna with inset (c) VSWR circular patch antenna with inset.

Furthermore, Fig. 5 (a) and Fig. 5 (b) show that the parameters S_{11} and VSWR of the circular patch antenna design with inset and slot can be controlled by changing the dimensions of L_i with a range of 2.8 mm – 4.8 mm and the dimensions of the slot L_s with range 3 mm – 5mm. The overall results of the iteration process of L_i and L_s are shown in Table 3 and Table 4.

Table 3. Simulation result from iteration of L_i

Iteration	L_i (mm)	Parameters					
		S_{11} (dB)		VSWR		BW (MHz)	
		f_{r1}	f_{r2}	f_{r1}	f_{r2}	f_{r1}	f_{r2}
1st iteration	2,8	-15,73	-10,10	1,42	1,97	128	286
2nd iteration	3,8	-14,74	-14,10	1,50	1,18	121	335
3rd iteration	4,8	-13,88	-23,07	1,45	1,54	111	316

Table 4. Simulation result from iteration of L_s

Iteration	L_s (mm)	Parameters					
		S_{11} (dB)		VSWR		BW (MHz)	
		f_{r1}	f_{r2}	f_{r1}	f_{r2}	f_{r1}	f_{r2}
1st iteration	4	-13,84	-23,14	1,87	1,14	114	319
2nd iteration	5	-13,77	-23,22	1,67	1,16	110	321
3rd iteration	6	-13,84	-23,24	1,57	1,17	114	319

Table 3 shows that the addition of the inset succeeded in producing an antenna with dual frequencies where f_{r1} = 3.5 GHz and f_{r2} = 6 GHz. Furthermore, the best performance of the proposed antenna is obtained in the 3rd iteration where the antenna operates at the frequencies f_{r1} = 3.5 GHz and f_{r2} = 6 GHz with S_{11} of -13.88 dB and -23.07 dB, VSWR 1.45 and 1.54 then has a bandwidth of 111 MHz and 316 MHz with dimensions of L_i = 4.8 mm. Furthermore, Table 4 shows the optimization of the antenna by controlling the dimensions of L_s where the best performance of the proposed antenna is obtained in the 3rd iteration with L_s = 6 mm where the antenna operates at the frequency f_{r1} = 3.5 GHz and f_{r2} = 6 GHz with S_{11} of - 13.84 dB and -23.24 dB, VSWR 1.57 and 1.17, then has a bandwidth of 114 MHz and 319 MHz. From the simulation results, it can be seen that the antenna operates at two resonant frequencies and has S_{11} and VSWR which meet the standards with $S_{11} \leq$ -10 dB and VSWR ≤ 2. Therefore, the next step is to design and simulate a MIMO antenna with 2 ports.

MIMO Antenna Design

The design of a 2-port MIMO antenna with a vertical configuration is shown in **Fig. 6**.

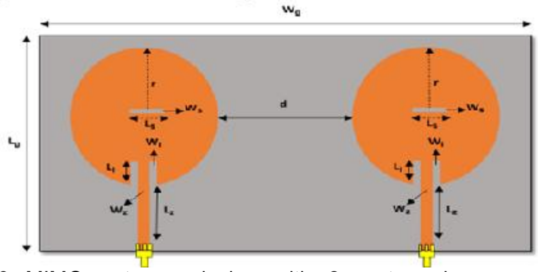

Fig. 6 MIMO antenna design with 2 ports using a vertical configuration

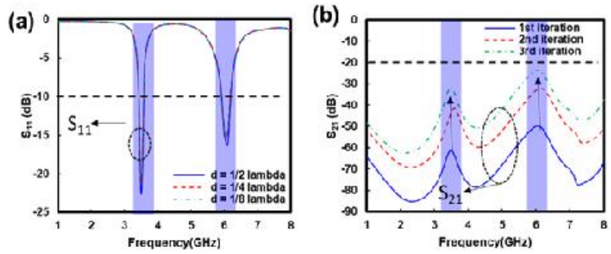

Fig 7. Simulation results of an antenna with a vertical configuration: (a) simulation of S_{11}, (b) simulation of S_{21}

The simulation results of the proposed antenna using a vertical configuration are shown in Fig. 7(a) and Fig. 7(b).

Fig.7 (a) and Fig.7 (b) show that parameter S_{11} of the antenna operating at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz is ≤ -10 dB while for S_{21} of the MIMO antenna is ≤ -20 dB using vertical configuration which can be controlled by adjusting the distance between the antenna patches (d) which is determined using equation (5) as follows [8]:

$$d = \frac{1}{4}\lambda \quad (5)$$

where *d* represents the distance between MIMO antennas and *λ* is the wavelength. The overall simulation results from the iteration of the distance *(d)* with the vertical configuration are shown in Table 5.

Table 5. Simulation results from iteration of *d*

Iteration	*d* (mm)	Parameters			
		S_{11} (dB)		S_{21} (dB)	
		f_{r1}	f_{r2}	f_{r1}	f_{r2}
1st iteration	40	-22,53	-14,68	-61,11	-49,98
2nd iteration	20	-21,10	-15,02	-41,98	-32,38
3rd iteration	10	-21,10	-15,18	-31,96	-23,81

Table 5 shows the best performance obtained in the second iteration where the antenna operates at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz with S_{11} of -21.10 dB and -15.02 dB and S_{21} of -41.98 dB and -32.38 dB. From the simulation results the MIMO antenna using a vertical configuration has succeeded in producing S_{21} ≤ -20 dB. Furthermore, to reduce S_{21} optimization is carried out by changing the configuration of the MIMO antenna.

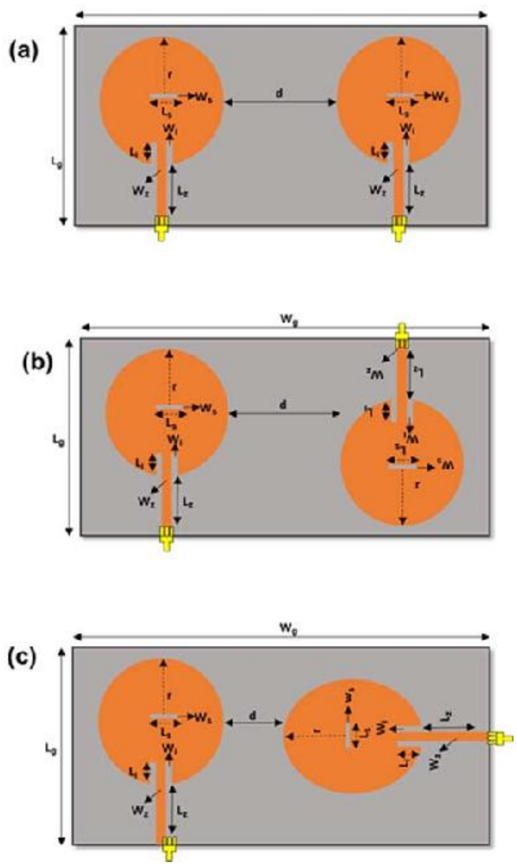

Fig. 8. Optimization design of a 2-port MIMO antenna: (a) with an angle of 0°, (b) with an angle of 180°, (c) with an angle of 90°

In this paper, optimization of the isolation coefficient parameter (S_{21}) is carried out by changing the configuration of the 2-port MIMO antenna. The mechanism used is to rotate one of the MIMO patch antennas with an angle of 90° and 180° and compare it with the initial antenna configuration with an angle 0°. Furthermore, the optimization design of the vertical-horizontal 2 port MIMO antenna is shown in **Fig.8**.

Fig. 8(a) shows the 1st iteration of the initial 2 port MIMO antenna design which uses a vertical configuration with a distance of *d* = 20 mm. Furthermore, the 2nd iteration is carried out by changing the configuration by rotating the MIMO patch antenna with a vertical orientation of 180° with a distance of *d* = 20 mm. Furthermore, the 3rd optimization is carried out by rotating the MIMO patch antenna with a vertical orientation of 90° with a distance of *d* = 20 mm. The purpose of this optimization is to obtain a high isolation coefficient (S_{21}). A high isolation coefficient indicates that MIMO antennas work independently so they have a low correlation and do not affect each other when operating simultaneously.

The simulation results of the optimization of the 2-port MIMO antenna design with a vertical - horizontal configuration are shown in Fig.9 (a) and Fig.9 (b).

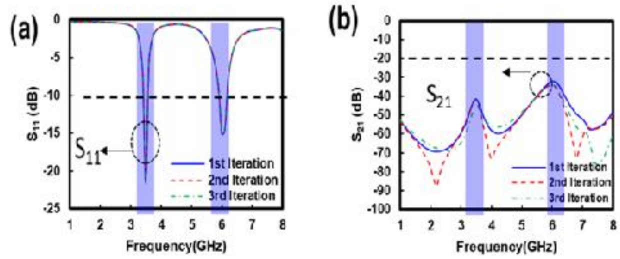

Fig. 9 Simulation result of MIMO antenna, (a) simulation result of S_{11}, (b) simulation result of S_{21}

Fig. 9 (a), Fig. 9 (b) shows that parameter S_{21} of the MIMO 2 port antenna optimization vertical - horizontal configuration can be controlled by rotating one of the MIMO patch antennas with an angle of 0°, 90° and 180°. Furthermore, the results of the entire iteration and optimization process of the configuration of the 2-port MIMO antenna is shown in Table 6.

Table 6. Simulation result from different configurations of MIMO antenna

Iteration	Parameters	
	S_{21} (dB)	
	f_{r1}	f_{r2}
1st iteration	-41,82	-32,38
2nd iteration	-43,37	-34,12
3rd iteration	-45,22	-34,28

Table 6 shows that the best performance of the 2-port MIMO antenna configuration was obtained in the 3rd iteration where S_{21} was -45.22 dB and 34.28 dB. From the simulation results, it can be concluded that the 2-port MIMO antenna in a vertical – horizontal configuration has worked at two resonance frequencies and has S_{11} ≤ -10 dB and S_{21} ≤ -20 dB. The next stage is the fabrication and measurement of the proposed antenna in the laboratory.

Measurement and Verification

The fabrication of the proposed antenna was carried out using a substrate type RO5880 with dielectric constant (ε_r) of 2.2, thickness (*h*) of 1.578 mm and loss tan (*tan δ*) of 0.0009. The fabricated antenna is shown in Fig.10.

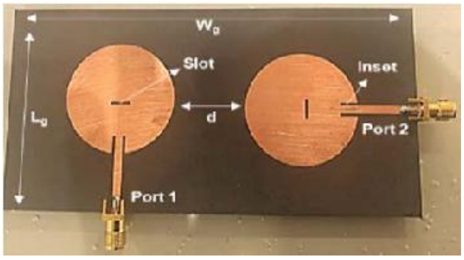

Fig 10. Fabricated proposed antenna

The measurement process was carried out using a *Vector Network Analyzer* (VNA) with a frequency range of 1 – 8 GHz with a sweep frequency of 0.01 GHz. The configuration of the measurement setup is shown in Fig. 11.

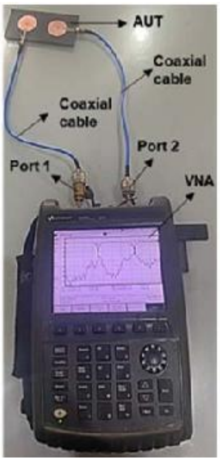

Fig 11. Measurement setup of proposed antenna

Fig.11 shows the VNA consisting of port 1 and port 2 which are connected directly to the Antenna Under Test (AUT) using a coaxial cable with an impedance of 50 Ohm. The measurement results of parameters S_{11} and S_{21} of the proposed antenna are shown on the VNA screen. The measurement results of the proposed MIMO antenna are shown in Fig. 12.

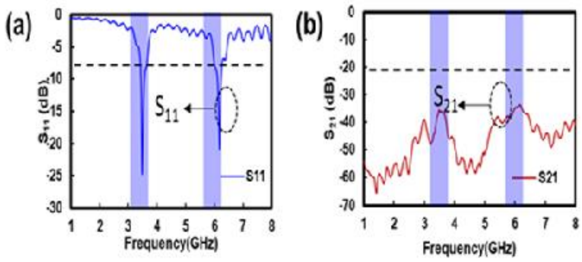

Fig 12. Measurement result of proposed antenna using VNA; (a) measurement result of S_{11}, (b) measurement result of S_{21} .

Fig.12 (a) and Fig.12 (b) shows that the parameter S_{11} of the proposed antenna at resonant frequencies of f_{r1} and f_{r2} are -24.61 dB and -20.84. Furthermore, S_{21} of proposed antena are -36.71 dB and -34.88 dB for each resonant frequency, respectively.

The next step is to validate and observe the performance of the proposed antenna. Validation was carried out by comparing the simulation and measurement results of parameters S_{11} and S_{21} of the proposed MIMO antenna. The comparison of the simulation and measurement processes of the proposed antenna are shown in Fig. 13.

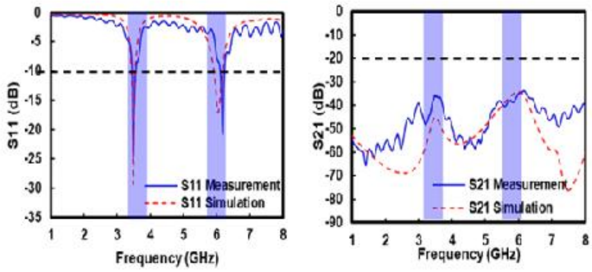

Fig. 13 Comparison of simulation and measurement, (a) comparison of S_{11}, (b) comparison of S_{21}.

Fig. 13 shows that the simulation results are in line with the measurement results. The simulation results show that the antenna operates at f_{r1} = 3.48 GHz and f_{r2} = 6.07 GHz while the measurements show that the antenna operates at f_{r1} = 3.52 GHz and f_{r2} = 6.18 GHz. This shows that there is a shift in the resonant frequency between the simulation and measurement processes of 1.15% and 1.78% for each resonant frequency. This is due to errors and inaccuracies in the fabrication process and connector installation so that the impedance of the antenna changes. Furthermore, for S_{11} from the simulation process on f_{r1} and f_{r2} obtained -29.45 dB and -17.16 dB while for the measurement process obtained -24.61 dB and -20.84 dB. This shows that the antenna meets the criteria with S_{11} ≤ -10 dB. Furthermore, S_{21} from the simulation process on f_{r1} and f_{r2} obtained -45.70 dB and -34.88 dB while the measurement process obtained -36.71 dB and -34.89 dB at each resonant frequency. The overall comparison results from the simulation and measurement processes are shown in **Table 7**.

Table 7. Comparison of resonant frequency of proposed antenna from simulation and measurement

Frequency (GHz)	Process		Error (%)
	Simulation	Measurement	
f_{r1}	3.48	3.52	1,15 %
f_{r2}	6.07	6.18	1,81 %

From the results shown in **Table 7** can be concluded that the designed antenna has the same characteristics for the simulation and measurement processes where the antenna has operated at two resonant frequencies with S_{11} ≤ -10 dB and S_{21} ≤ -20 dB. The next step is to evaluate the performance of the MIMO antenna by observing the *Envelope Correlation Coefficient* (ECC) and *Diversity Gain* (DG) parameters.

ECC shows the correlation between the two antennas when working together for the MIMO configuration. Generally, the ECC range used is in the range 0 - 1. Furthermore, the threshold value of the ECC that is commonly used in a MIMO antenna design is ≤ 0.5 [17]. ECC parameters can be determined using equation (6) as follows:

$$\text{(6)} \qquad ECC = \frac{|S_{11}{}^{*}S_{12}+S_{21}{}^{*}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)-(1-|S_{22}|^2-|S_{12}|^2)}$$

Diversity Gain (DG) describes the ability to deal with multipath fading. The DG value describes the ability to increase or maintain the signal against noise when combining all signals on the antenna rather than on one antenna. The diversity of MIMO antennas is indicated by DG ≤ 10 dB [18]. DG can be determined based on equation (7) as follows:

$$\text{(7)} \qquad DG = 10\sqrt{1-(ECC)^2}$$

Fig.14 shows a comparison of the ECC and DG at the two resonant frequencies of the proposed antenna. Based on the calculation results, the ECC on f_{r1} and f_{r2} is 0.0018 and 0.0012 while for DG it is 10 dB and 9.99 dB. This shows that the ECC and DG of the designed antenna have met the target set where ECC ≤ 0.5 and DG ≤ 10 dB. From these results it can be concluded that the designed MIMO antennas have a low correlation coefficient, so they do not affect each other when working together.

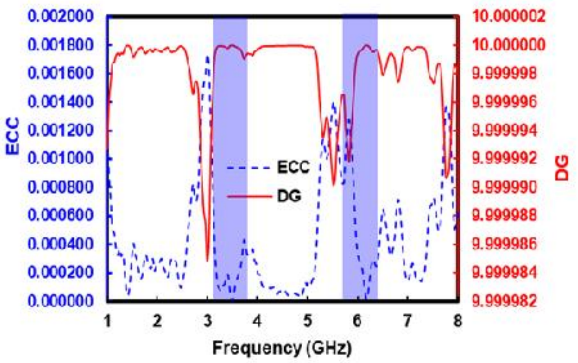

Fig. 14 ECC and DG from proposed antenna

Furthermore, the simulation results of the gain and radiation pattern of the proposed antenna are shown in Fig. 15.

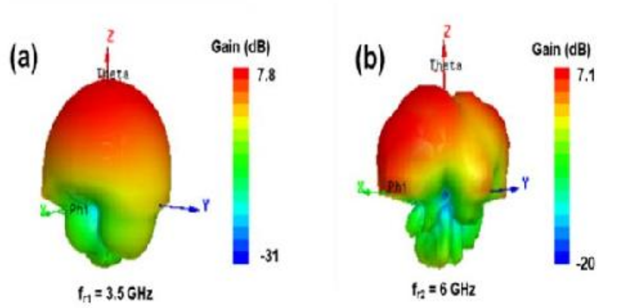

Fig. 15 Radiation pattern and gain of proposed antenna, (a) at f_{r1} = 3.5 GHz, (b) at f_{r2} = 6 GHz.

Fig. 15 (a) and Fig. 15 (b) show that the proposed antena has a maximum gain of 7.8 dB and 7.1 dB for f_{r1} = 3.48 GHz and f_{r2} = 6.18 GHz. Furthermore, Table 8 is proposed to show the novelty of this study compared to previously proposed studies.

Table 8.

Ref.	Freq. (GHz)	Paramaters				MIMO	*Dual Band*
		S_{11} (dB)	S_{21} (dB)	ECC	DG (dB)		
[13]	4.45	-45	NA	NA	NA	No	No
[15]	3.5	-14	-19.25	NA	NA	Yes	No
[14]	3.5	-17.43	NA	NA	NA	No	No
[16]	0.7 2.3	-30 -15	-31.37 -14.26	0,127 0,007	NA	Yes	Yes
This work	3.52 6.18	-24,61 - 20.84	-36,71 -34.88	0,0018 0.0012	10 9.99	Yes	Yes

Table 8 shows that the proposed antenna has a novelty that can operate at two different resonance frequencies with low ECC and high DG. In addition, the proposed antenna has been configured in MIMO so that it can be recommended for 5G communication systems.

Table 8. Comparison result with previous studie

Conclusion

This paper has described the realization of a 2-port MIMO microstrip antenna with a circular patch that operates at two resonant frequencies, namely f_{r1} = 3.5 and f_{r2} = 6 GHz. The slot and inset methods are proposed to control parameter S_{11} and the resonant frequency of the antenna, while the vertical-horizontal configuration is proposed to reduce parameter S_{21}. From the measurement results it was found that S_{11} was -24.61 dB and -20.84 dB while for S_{21} it was -36.71 dB and -34.88 dB for each resonant frequency. Furthermore, the ECC was obtained, namely 0.0018 and 0.0012 and DG of 10 dB and 9.99 dB for f_{r1} and f_{r2}, respectively. From these results it can be concluded that the designed antenna meets the specified targets, namely S_{11} ≤ -10 dB, S_{21} ≤-20 dB, ECC ≤ 0.5 and DG ≤ 10 dB. This research is very useful and can be recommended as a receiving antenna for 5G communication systems.

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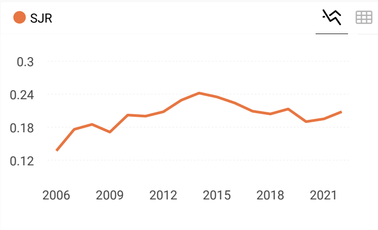

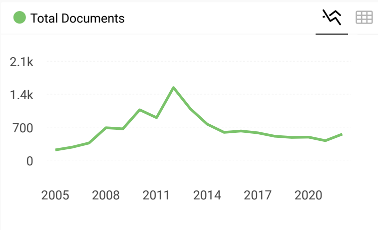

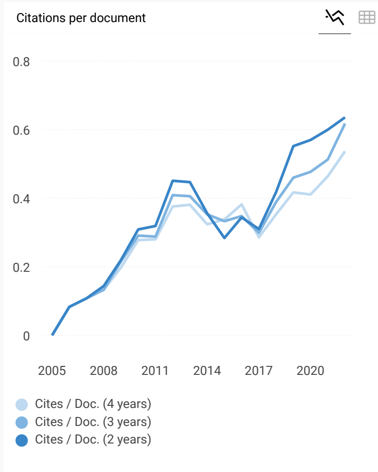

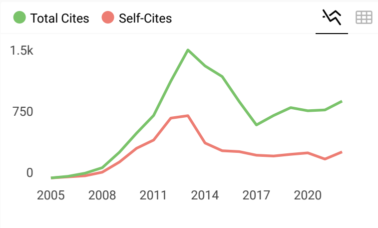

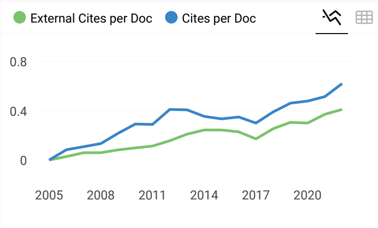

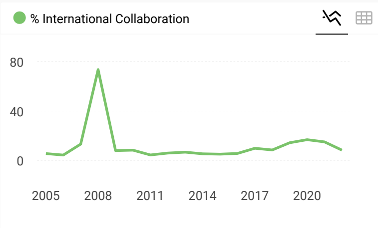

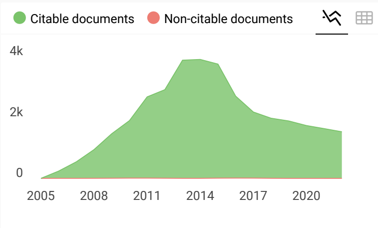

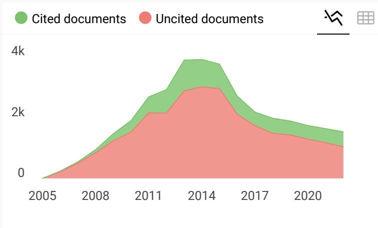

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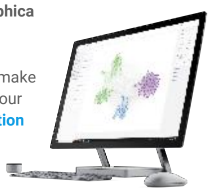

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