



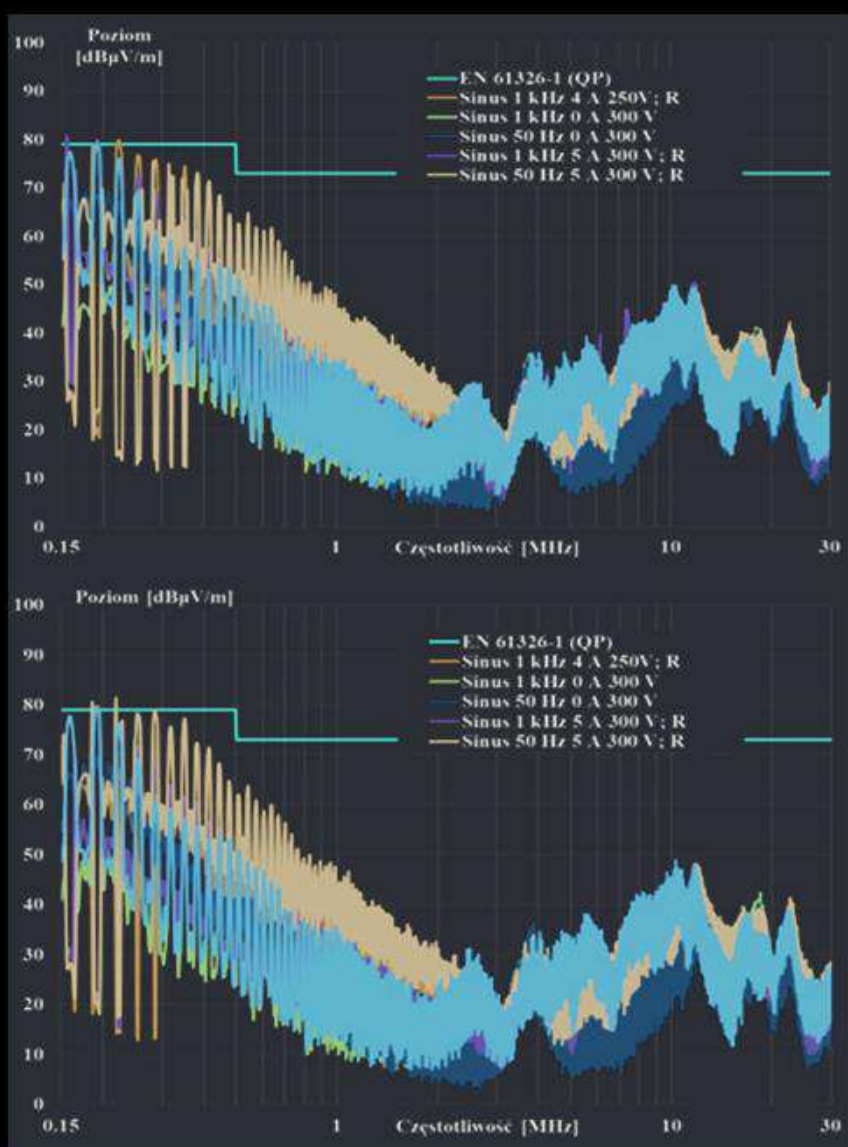
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"Przegląd Elektrotechniczny" exists since 1919 and it is one of the oldest Polish scientific journals. It is dedicated to electrical engineering. The owner of the title is SEP (Society of Polish Electrical and Electronics Engineers).

Przegląd Elektrotechniczny is published monthly in average 200 pages per issue (120 - 300 pages). We publish the papers in Polish or English. The Scientific Level of our Journal is controlled by 44-person Program Editorial Board.

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Contents

01	Konrad DĄBAŁA, Maciej BOGUMIŁ - Increasing the Efficiency of a High-efficiency Squirrel-cage Induction Motor with Semi-closed Slots by Casting the Slots with Ferro-resin Instead of Using Permanent Magnetic Wedges	1
02	Henryk KOCOT, Agnieszka DZIENDZIEL - Analysis of the flow of currents in lightning conductors of the multi-circuit, multi-voltage high and highest voltage overhead lines – part 1	6
03	Henryk KOCOT, Agnieszka DZIENDZIEL¹ - Analysis of the flow of currents in lightning conductors of the multi-circuit, multi-voltage high and highest voltage overhead lines – part 2	12
04	Łukasz KAJDA, Sebastian SAMUL - LV regulation using MV/LV transformer with on-load tap changer, based on voltage measurements from AMI meters	16
05	Ammar DJERIOUI, Makhlof DJERIOUI - Energy Management in a Proton Exchange Membrane Fuel Cell-based DC Microgrid Using Feedback Linearization Control and GWO	20
06	Mohamad Faizal Baharom, Mohd Fauzi Ab Rahman, Anas Abdul Latiff, Aminah Ahmad, Mohd Hafiz Jali, Sulaiman Wadi Harun - Q-Switching in an Erbium-Doped Fibre Laser Using a Saturable Absorber Based on Vanadium Pentoxide Polyethylene Glycol in the Long-Wavelength Range	27
07	Amina BAGDAOUI, Amina BENDAOUDI, Ali JAFFARI - Intensity Only Multi-Materials Image Reconstruction	31
08	Walid Mohammed KACEMI, Elhadj BOUNADJA, Abdelkadir BELHADJ DJILALI, Belkacem SELMA - Enhancing Wind Energy Conversion Efficiency with Parallel Hybrid Excitation Synchronous Generators based on Second-Order Sliding Mode Control	37
09	Piotr Kaczmarek - Electromagnetic compatibility of power supplies providing generation of AC voltage over a wide frequency range	43
10	Marek FLORKOWSKI - The influence of a magnetic field on the dynamics of partial discharges in high-voltage insulation system	49
11	Tuan-Ho LE, Nguyen Nhan BON - Bi-objective robust design optimization for LED lens design	55
12	Feby Agung Pamuji, Prisma Riashuda Prakosa, Heri Suryoatmojo, Nurvita ARUMSARI, Mohammad Khoirul Effendi, Bambang Sudarmanta, Kevin Dwi Prasetyo – Design and Implementation of Buck Boost Converter for fuzzy Logic Controller Based DC Motor Speed Control	60
13	Makmur SAINI, Muhammad Ruswandi DJALAL, A.M.Shiddiq YUNUS, Andreas PANGKUNG - FACTS Devices Optimization for Optimal Power Flow Using Particle Swarm Optimization In Sulselrabar System	67
14	Laaredj GHAOUTI, Nadir BOUCHETATA, Bachir DAAOU - Field oriented control technique applied to the PMSM without mechanical sensor, based on the cubature KALMAN filter observer	72
15	Bait Fateh, Latreche Samia, Khemliche Mabrouk, Boulemzaoud Lokmane - Diagnosis of a stand-alone photovoltaic installation by the Analytical Redundancy Relationship method (ARR)	78
16	Milan Belik, Vadym Hulevskiy, Yulia Postol, Olena Rubanenko - Ways to improve the efficiency of cleaning cutting fluids	83
17	Salsanabila Mariestiara PUTRI, Indra SURJATI, Syah ALAM, Yuli Kurnia NINGSIH, Lydia SARI, Teguh FIRMANSYAH, Zahriladha ZAKARIA - High Isolation of Dual-Band MIMO Microstrip Antenna with Vertical – Horizontal Configuration for 5G Communication System	87
18	Madi Said, Kherief Nacereddine Mohamed, Mohand Said LARABI - Robust linear LQG control for a multi-variable wind turbine system subject to parametric perturbation	94
19	Olga KOŁECKA - Methods of detecting defects using infrared thermography	101
20	Jacek KOZYRA, Zbigniew ŁUKASIK, Aldona KUŚMIŃSKA-FIJAŁKOWSKA, Piotr TAŃSKI - An analysis of elimination of interferences in the supply system of an industrial plant	105
21	Boumediene SAIED, Abdelfatah NASRI, HAMZATedjini, Hicham CHERGUI, Kayisli KORHAN - Pioneering Battery-Supercapacitor Hybrid Energy Management for E-Scooters for Sustainable Urban Transportation	113
22	Charinsak SAETIAW, Suthasinee LAMULTREE, Jatuporn NAKORNTEP, Suwit PHUCHADUEK - The Design of Capsule-Shaped Patch Antenna with Multiple Rectangular Slotted for 3D Printing Technology using Conductive PLA Material	118
23	Mostefa BECHEIKH, Said HASSAIN - Co-Simulation of permanent magnet synchronous motor with demagnetized fault fed by PWM inverter	124
24	Samir HABIBES, Ahmed Wahid BELARBI, Naima OUSSALAH - Influence of Corona layer on Corona Computation in Wire to Plane System	128
25	Mustafa Murtdha Al-saeedi, Taha Raad Al-Shaikhli, Wisam Raad Ahmed, A. M. Ibrahim, Ahmed Raed Al-Tamimi, Noor Azwan Shairi - Design and Analysis of Three Thin Patch Antenna for Wireless Application	132
26	Přemysl JANŮ, Petr BÍLÝ - An access system for small family buildings	136
27	Kadri Nadjib, Krika Wafa, Kadir Erkan, Ahmet Fevzi Bozkort, Ayad Ahmed Nour El Islam, Sabri Khelifa, Abdelmajid Rais, Rouibah Taha - Experiment realization and simulation of new vertical rotating disk of eddy current separator	142
28	Saidjon TAVAROV, Ziad EL KHATIB, Firuz KAMALOV, Aleksandr SIDOROV, Rustam VALEEV, Murodbek SAFARALIEV - Method of forecasting and calculation of electric load of utilities and household consumers under uncertainty	148
29	Abdelghani ROUINI, Messaouda LARBI, Derradji BAKRIA, Belkacem KORICH - A Neural Network Designed for COVID-19 Detection Using CT Images	152
30	Nuchanart SANTALUNAI, Samroeng SANTALUNAI, Samran SANTALUNAI, Chanchai THONGSOPA, Weerawat CHAROENSIRI, Jariya PAKPROM, Thanaset THOSDEEKORAPHAT, Pichaya CHAIPANYA - Effect of Electric field on Dielectric Loads by Using the Electrode Plates for Exterminating Pests Applications	156

Contents

31	Soraya GOUDER, Laatra YOUSFI, Dhaouadi GUIZA, Ramdane MAHAMDI, Isabelle BERBEZIER - Optimizing SiGe-on-annealed DPSi Heterostructures Using Raman Spectroscopy and Genetic Algorithm for Enhanced Material Characterization and Performance	165
32	Ahmed Jamal Abdullah Al-Gburi - 5G MIMO Antenna: Compact Design at 28/38 GHz with Metamaterial and SAR Analysis for Mobile Phones	171
33	Henryk WACHTA, Sebastian RÓŻOWICZ², Lubomir BENA - Analysis of reflections of multiple elementary rays in computer design of floodlighting	175
34	Abd Majid DARSONO, Nurul Husna MAT YAZI, Abd Shukur JA'AFAR, Mohd Azlishah OTHMAN, Muhammad Imran AHMAD - Utilizing LSTM Networks for the Prediction of Driver Behavior	182
35	MESSABIH Mohamed, DAAOU Bachir, KACIMI Abderrahmane - High order Sliding control with High order observer applied on a bioreactor	186
36	Faiçal KHARCHOUCHE, Abdelkrim ZEBAR - Effect of Fe ₂ O ₃ doping on the electrical and microstructural properties of ZnO-(Bi ₂ O ₃ , Sb ₂ O ₃) varistor ceramics	192
37	Marek GAŁA, Antoni SAWICKI, Lubomir MARCINIAK - Influence of disturbances of arc parameters on the degree of deformation of signals in an electric circuit	197
38	Patryk GAŁUSZKIEWICZ, Zbigniew GAŁUSZKIEWICZ¹ - Energy storage in electrochemical storage based on LiFePO ₄ and LTO batteries	201
39	Patryk GAŁUSZKIEWICZ - Energy storage in microgrid systems using heat pumps and storage of electricity and heat	205
40	Mirosław KORNATKA, Radosław WITKOWICZ - Technical and economic analysis of reactive power compensation in an industrial plant	209
41	Maciej SOŁTYSIK - Selected functional models of energy communities	213
42	Roman SIKORA, Przemysław MARKIEWICZ, Ewa KORZENIEWSKA, Alyona NIKITINA - Calculation of electric shock current caused by touch and step voltage in grounding grids including climatic conditions	217
43	Mekkaoui Mohammed¹, Zemalache Megueni Kadda - Dynamic Sliding Mode and Backstepping controllers for Trajectory Tracking of Mobile Robot Wheeled	221
44	Samir LADJOUZI, Mohamed REZKI - Active mode detection for hybrid systems using feed- forward neural networks	226
45	Shanmugavadivu Natarajan - Efficient High Voltage Gain Simplified DC-DC Converter for Enhanced Solar Power Harvesting	229
46	Konrad NIDERLA², Grzegorz KŁOSOWSKI - Learning environment with reinforcement for industrial robot arm control	233
47	Marcin DZIADOSZ, Mariusz MAZUREK, Barbara STEFANIAK, Dariusz Wójcik, Konrad Gauda - A comparative study of selected machine learning algorithms for electrical impedance tomography	237
48	Michał GOŁĄBEK, Bartłomiej BARAN, Piotr BOŻEK, Daria STEFAŃCZAK, Dariusz WÓJCIK - Design features of a portable ultrasonic-impedance tomograph for bladder monitoring	241
49	Dominik GNAŚ, Michał STYŁA, Przemysław ADAMKIEWICZ, Wiktoria ZAWADZKA - In-building object tracking and tracing using ultra-wideband technology and temporal distance scaling methods	245
50	Marcin DZIADOSZ, Mariusz MAZUREK, Oleksii HYKA, Marcin KOWALSKI, Dariusz WÓJCIK - Development and implementation of algorithms for measurement and reconstruction analysis in ultrasound tomography	249
51	Michał MAJ, Damian PLISZCZUK, Tomasz CIEPLAK, Łukasz MACURA - Comparison of CIE CAM and CIE LAB color space models for better automation of optical quality control	253
52	Konrad KANIA, Mariusz MAZUREK, Grzegorz KŁOSOWSKI, Józef STOKŁOSA - Imaging Enhancement Through Deep Learning Aided Decompression in Ultrasound Tomography	257
53	Kamila BIAŁEK, Jacek JAKUBOWSKI, Anna POTULSKA-CHROMIK, Monika NOJSZEWSKA, Anna KOSTERA-PRUSZCZYK - The application of convolutional neural networks in the diagnosis of Parkinson's disease on the basis of handwriting samples	261
54	Paweł BIEŃKOWSKI - Electromagnetic field of broadcasting systems yesterday and nowadays	265
55	Artur BOGUTA - Building automation control using mobile device	269
56	Borys BOROWIK¹, Marek KĘSY - Dynamics of electrodynamic metal shaping taking into account the waviness of surface deformation	273
57	Marcin BUCZAJ, Andrzej SUMOREK, Agnieszka BUCZAJ - The functioning of energy storage facilities as systems that reduce the costs of purchasing electricity	277
58	Serhiy SYROTYUK, Vitaliy BOYARCHUK, Serhii KOROBKA, Vadym PTASHNYK, Serhii BARANOVYCH, Roman SHEREMETA, Hanna SYROTYUK, Viktor CHUMAKEVYCH, Jan GIEŁŻECKI, Tomasz JAKUBOWSKI, Paweł SOKOŁOWSK - Design and Research of Computer Model of Wind Turbine Using LabVIEW	281
59	Sylwester FILIPIAK - Application of the evolutionary-fireworks algorithm to optimize power flows in power systems	286
60	Mohamed FAWZY, Hani ATTAR, Ayman AMER, Sameh ALSAQOOR, Ali ALAHMER, Gabriel BOROWSKI, Ahmed A.A. SOLYMAN, Samer AS'AD, Ramy Said AGIEB - Comparison of the Performance of PID and TVLQR Controllers for Nonlinear Modelling of a Freedom Flying Body	291

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.

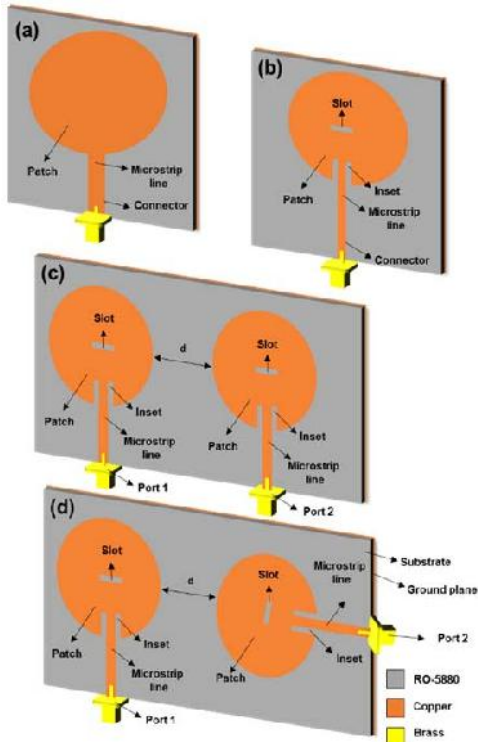


Fig. 1 Model development of the antenna; (a) single element circular patch antenna design, (b) circular patch antenna design with inset and slot, (c) 2 port MIMO antenna design with vertical configuration, (d) 2 port MIMO antenna design with vertical-horizontal configuration

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].

$$(1) \quad F = \frac{8,791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

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).

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

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 50Ω are determined using equation (3) and equation (4) [17].

$$(3) \quad B = \frac{60 \pi^2}{Z_0 \sqrt{\epsilon_{\text{reff}}}}$$

$$(4) \quad W_z = \frac{2h}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\epsilon_r}{2\epsilon_r} \left[\ln(B - 1) + 0,39 - \frac{0,61}{\epsilon_r} \right] \right\}$$

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.

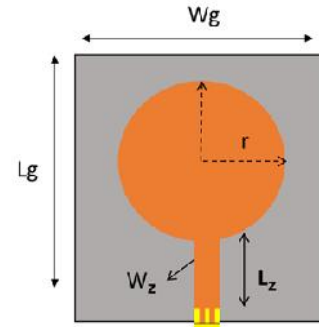


Fig. 2 Design of a circular patch microstrip antenna

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).

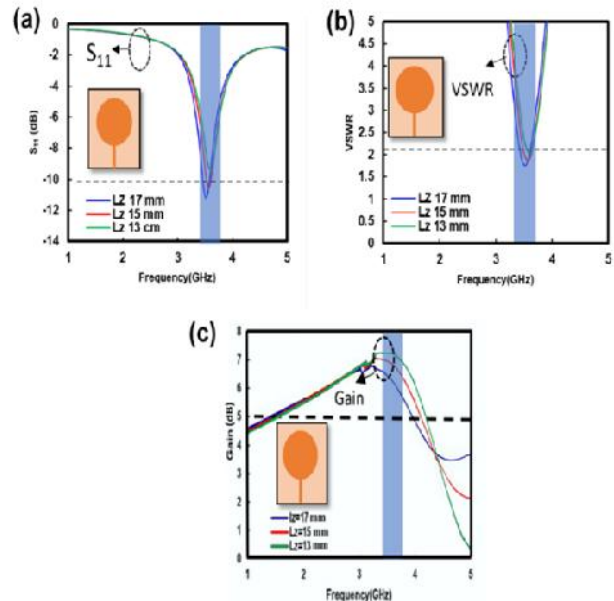


Fig. 3 Simulation results of circular microstrip patch antenna; (a) S_{11} of proposed antenna (b) VSWR of proposed antenna, (d) gain of proposed antenna

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.

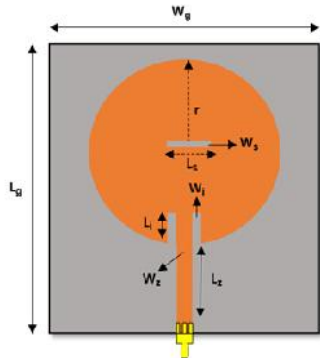


Fig. 4. Design of circular patch microstrip antenna with inset and slot

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 .

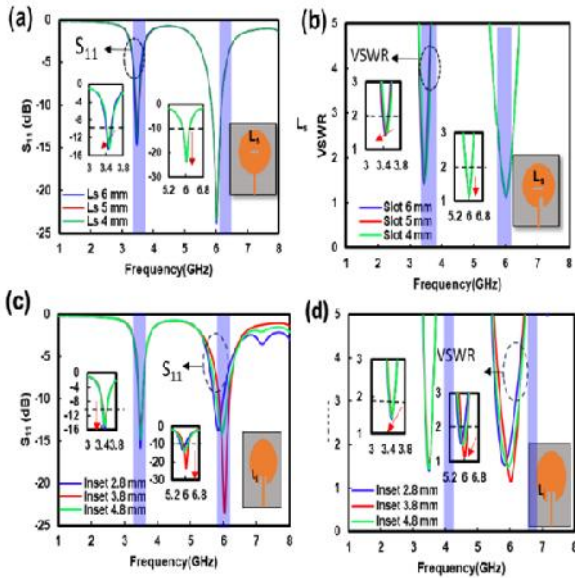


Fig. 5 Design simulation results of circular patch antenna with inset and slot (a) S_{11} circular patch antenna with slot, (b) VSWR circular patch antenna with slot, (c) S_{11} circular patch antenna with inset (c) VSWR circular patch antenna with inset.

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}
1 st iteration	2,8	-	-10,10	1,42	1,97	128	286
2 nd iteration	3,8	-	-14,10	1,50	1,18	121	335
3 rd iteration	4,8	-	-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}
1 st iteration	4	-13,84	-23,14	1,87	1,14	114	319
2 nd iteration	5	-13,77	-23,22	1,67	1,16	110	321
3 rd 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 $VSWR \leq 2$. 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.

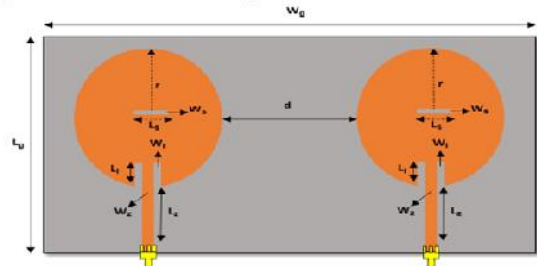


Fig. 6 MIMO antenna design with 2 ports using a vertical configuration

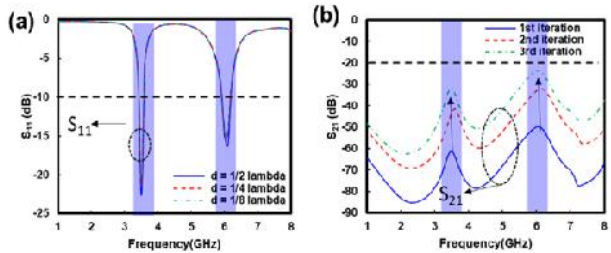


Fig 7. Simulation results of an antenna with a vertical configuration: (a) simulation of S_{11} , (b) simulation of S_{21}

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]:

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

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}
1 st iteration	40	-22,53	-14,68	-61,11	-49,98
2 nd iteration	20	-21,10	-15,02	-41,98	-32,38
3 rd 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 $S_{21} \leq -20$ dB. Furthermore, to reduce S_{21} optimization is carried out by changing the configuration of the MIMO antenna.

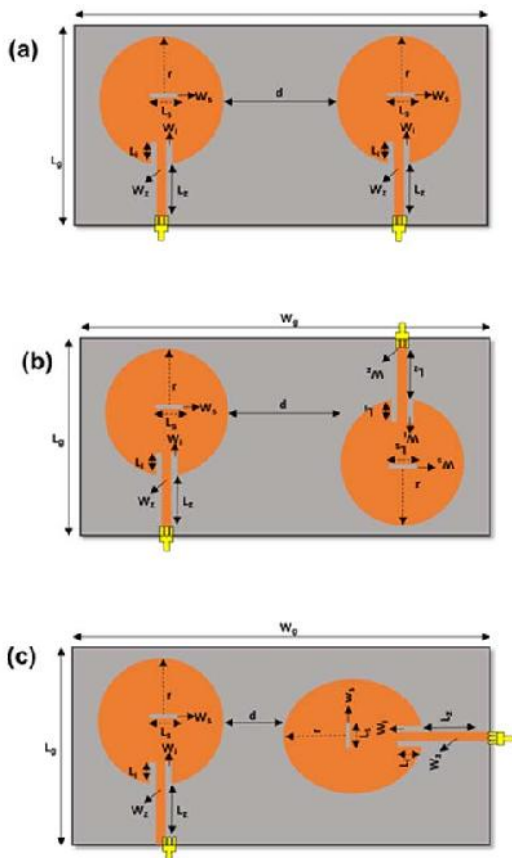


Fig. 8. Optimization design of a 2-port MIMO antenna: (a) with an angle of 0° , (b) with an angle of 180° , (c) with an angle of 90°

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).

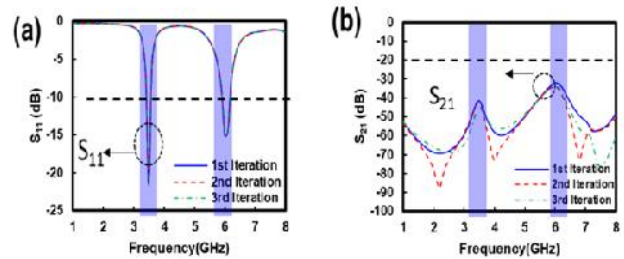


Fig. 9 Simulation result of MIMO antenna, (a) simulation result of S_{11} , (b) simulation result of S_{21}

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}
1 st iteration	-41,82	-32,38
2 nd iteration	-43,37	-34,12
3 rd 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 $S_{11} \leq -10$ dB and $S_{21} \leq -20$ 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 ($\tan \delta$) of 0.0009. The fabricated antenna is shown in Fig.10.

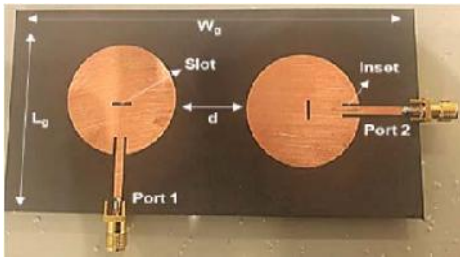


Fig 10. Fabricated proposed antenna

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.

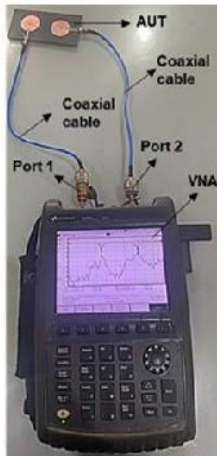


Fig 11. Measurement setup of proposed antenna

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.

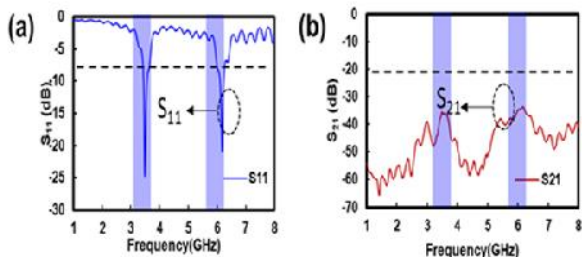


Fig 12. Measurement result of proposed antenna using VNA; (a) measurement result of S_{11} , (b) measurement result of S_{21} .

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 antenna 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.

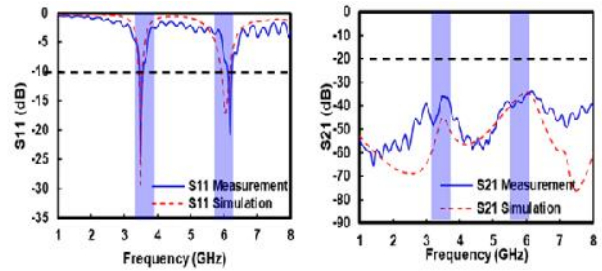


Fig. 13 Comparison of simulation and measurement, (a) comparison of S_{11} , (b) comparison of S_{21} .

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 $S_{11} \leq -10$ 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 $S_{11} \leq -10$ dB and $S_{21} \leq -20$ 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:

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

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 $DG \leq 10$ dB [18]. DG can be determined based on equation (7) as follows:

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

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 $ECC \leq 0.5$ and $DG \leq 10$ 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.

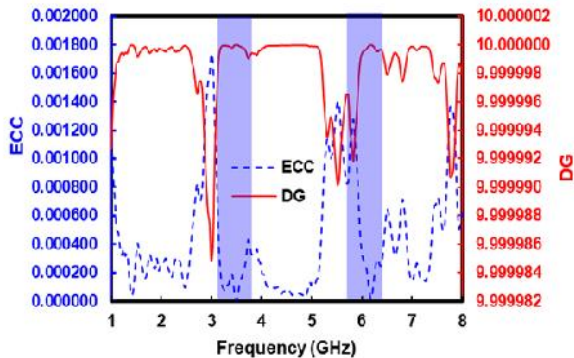


Fig. 14 ECC and DG from proposed antenna

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

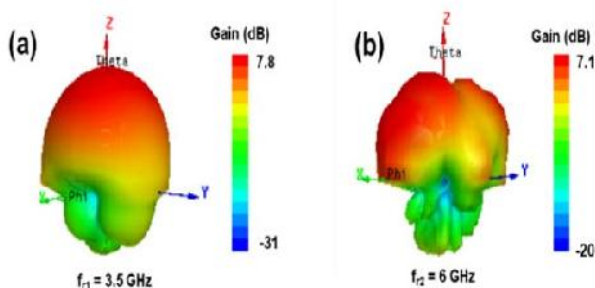


Fig. 15 Radiation pattern and gain of proposed antenna, (a) at f_{r1} = 3.5 GHz, (b) at f_{r2} = 6 GHz.

Fig. 15 (a) and Fig. 15 (b) show that the proposed antenna 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)	Parameters				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 $S_{11} \leq -10$ dB, $S_{21} \leq -20$ dB, $ECC \leq 0.5$ and $DG \leq 10$ dB. This research is very useful and can be recommended as a receiving antenna for 5G communication systems.

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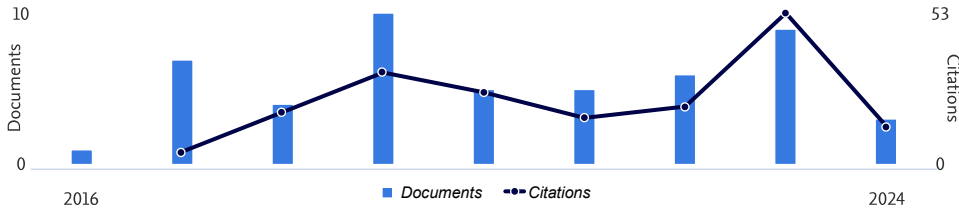
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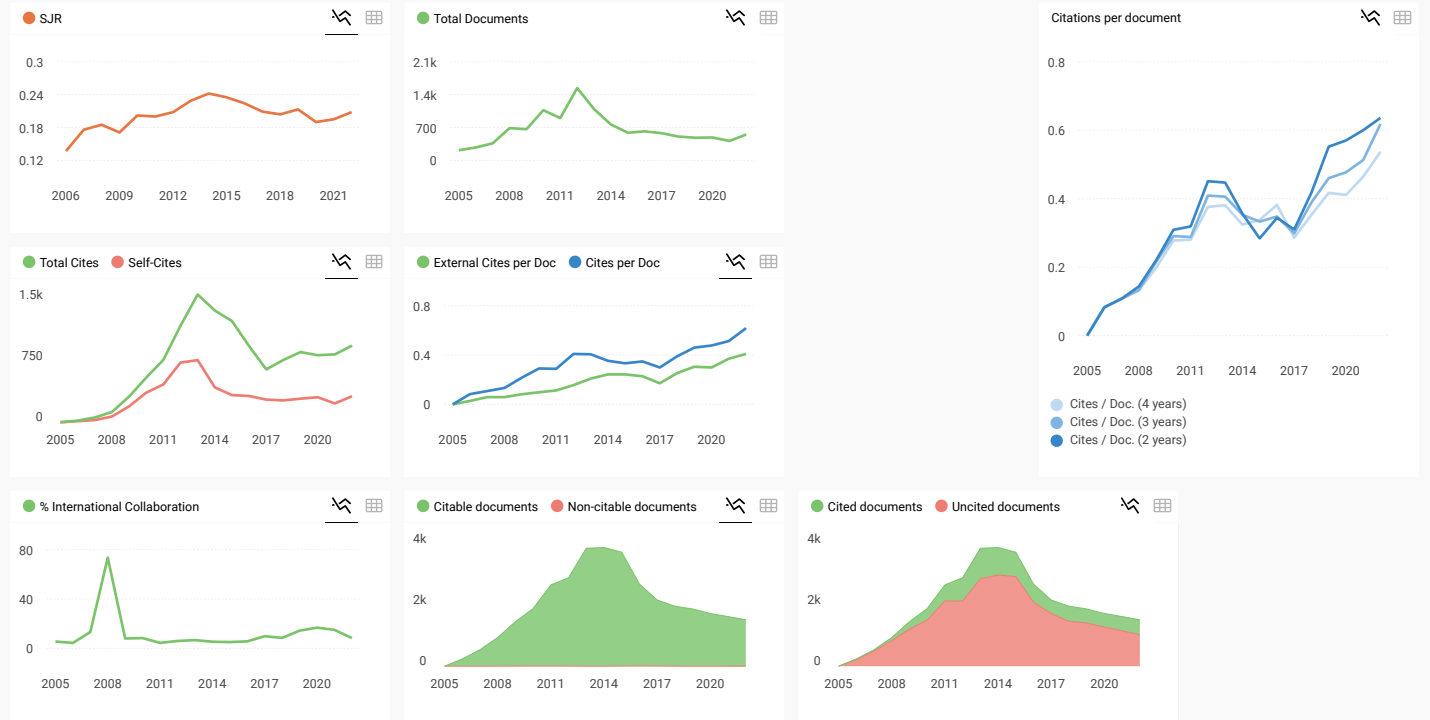
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Mon, Nov 13, 2023 at 12:38 PM

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Prof. Slawomir TUMANSKI
Editor in Chief
Przegląd Elektrotechniczny Journal

Together with this letter we want to sent proof of payemnet of our paper that has been accepted in Przegląd Elektrotechniczny Journal (PE7425 : High Isolation of Dual-Band MIMO Microstrip Antenna with Vertical – Horizontal Configuration for 5G Communication System) via paypal. Please feel free to contact us about the progress of our paper.

Regard

Syah Alam

[Quoted text hidden]

 **PayPal_ Transaction Details PEL 479.pdf**
89K

ST <tumanski@tumanski.pl>
Reply-To: tumanski@tumanski.pl
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Mon, Nov 13, 2023 at 10:40 PM

We received payment for 7425 – thank you.

[Quoted text hidden]



REFeree REPORT

Manuscript reference: 7425

Author

Title:

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

Please indicate mark from 0 to 10.

1. Does the paper represent an original contribution to the field of interest of electrical engineering: yes
2. Is the paper of good scientific quality and free from obvious errors: yes
3. Is the paper clear, concise and well organized: yes
4. Do the authors place the paper in proper context by citing previous relevant papers: yes
5. Does the abstract adequately summarize the work and the main conclusions: yes
6. Are figures and tables clear and relevant and captions adequate: yes
7. Is the paper written in correct English: yes
8. Are the conclusions supported by experimental evidence, computed results or prior publications: yes
9. To what extent is the material in the paper likely to be of interest by other researcher in the field
 - a. Very Much:
 - b. Much:**
 - c. Average:
 - d. Little:
 - e. Never:
10. Recommendation
 - a. Accept as it is**
 - b. Accept with minor changes
 - c. Accept subject to required revision
 - d. Do not publish

Please put additional remarks on the next page. Comments are strongly encouraged.

Referee (only for the editor knowledge):