

Home > About the Journal > **Editorial Policies**

Editorial Policies

- » [Focus and Scope](#)
- » [Section Policies](#)
- » [Peer Review Process](#)
- » [Open Access Policy](#)
- » [Archiving](#)
- » [Publication Ethics and Publication Malpractice Statement](#)
- » [Article acceptance requirements](#)
- » [Checklist for preparing your paper for publication](#)
- » [Authorship](#)
- » [Withdrawal of Manuscripts](#)
- » [Retraction and Correction policies](#)
- » [TELKOMNIKA Profile in Scimago and Google Scholar](#)

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TELKOMNIKA (Telecommunication Computing Electronics and Control) publishes six issues per year (February, April, June, August, October and December). The aim of TELKOMNIKA is to publish **high-quality articles** dedicated to all aspects of the latest outstanding developments in the field of electrical & electronics engineering, and computer science **from authors world-wide**. Its scope encompasses the engineering of telecommunication, computing, electrical & electronics, and instrumentation & control, which covers, but not limited to, the following scope:

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JOURNAL CONTENT

Search

Search Scope

All

[Search](#)

Browse

- By Issue
- By Author
- By Title

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Home > Archives > Vol 15, No 3

Vol 15, No 3

September 2017

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Table of Contents

| | |
|--|---------------------|
| The Correlation of Statistical Image and Partial Discharge Pulse Count of LDPE-NR Composite | PDF |
| <i>Aulia Aulia, Zulkarnain Abdul Malek, Yanuar Zulardiansyah Arief, Eka Putra Waldi</i> | 977-983 |
| Neural Network-Based Stabilizer for the Improvement of Power System Dynamic Performance | PDF |
| <i>Rudy Gianto, Kho Hie Khwee</i> | 984-994 |
| Thermal Condition and Losses in Ultra-High-Speed Generators | PDF |
| <i>Flur Ismagilov, Viacheslav Vavilov, Ruslan Karimov, Denis Gusakov</i> | 995-1002 |
| A Three-Phase Grid-Connected PV System Based on SAPF for Power Quality Improvement | PDF |
| <i>Rachid Belaidi, Ali Haddouche, Djamilia Ghribi, M. Mgezzi Larafi</i> | 1003-1011 |
| Noise Analysis in VLC Optical Link based Discrete OP-AMP Trans-impedance Amplifier (TIA) | PDF |
| <i>Syifaul Fuada, Trio Adiono, Angga Pratama Putra, Yulian Aska</i> | 1012-1021 |
| Weighted Least Squared Approach to Fault Detection and Isolation for GPS Integrity Monitoring | PDF |
| <i>Ershen Wang, Fuxia Yang, Pingping Qu, Tao Pang, Xiaoyu Lan</i> | 1022-1030 |
| The Performance of an Integrated Transformer in a DC/DC Converter | PDF |
| <i>Abdelhadi Namoune, Azzedine Hamid, Rachid Taleb</i> | 1031-1039 |
| Application Profiling and Mapping on NoC-based MPSoC Emulation Platform on Reconfigurable Logic | PDF |
| <i>Jia Wei Tang, Yuan Wen Hau, Nasir Shaikh-Husin, Muhammad Nadzir Marsono</i> | 1040-1047 |
| An Improved Repetitive Control for Circulating Current Restraining in MMC-MTDC | PDF |
| <i>Yahui Wang, Yijia Cao, Yong Li, Chang Li</i> | 1048-1060 |
| Packet Loss Rate Differentiation in slotted Optical Packet Switching OCDM/WDM | PDF |
| <i>Omar Najah, Kamaruzzaman Seman, Khairi Abdulrahim</i> | 1061-1071 |
| 94 GHz Millimeter Wave Conducted Speech Enhancement | PDF |
| <i>Sheng Li, Fuming M. Chen, Jinyan Hu, Hongbo Li, Lijun Qiu, Ying Tian, Jianqi Wang</i> | 1072-1078 |
| Design of Circular Patch with Double C-Shaped Slot Microstrip Antenna for LTE 1800 MHz | PDF |
| <i>Yusnita Rahayu, Jherino Permana Putra</i> | 1079-1082 |
| Design LTE Microstrip Antenna Rectangular Patch with Beetle-Shaped Slot | PDF |
| <i>Yusnita Rahayu, Haziq Hazman, Razali Ngah</i> | 1083-1087 |
| Wireless Body Area Networks for Healthcare Applications: An Overview | PDF |
| <i>Muhammad Anwar, Abdul Hanan Abdullah, Kashif Naseer Qureshi, Abdul Hakeem Majid</i> | 1088-1095 |
| Malicious User Attack in Cognitive Radio Networks | PDF |
| <i>N. Armi, S. Rizvi, W.Z. Khan, H. Zangoti, W. Gharibi, C. Wael</i> | 1096-1102 |
| Profile of Single Mode Fiber Coupler Combining with Bragg Grating | PDF |
| <i>Romi Fadli Syahputra, Saktioto Saktioto, Ros Meri, Syamsudhuha Syamsudhuha, Okfalisa</i> | 1103-1107 |
| Planar Microwave Sensors for Accurate Measurement of Material Characterization: A Review | PDF |
| <i>Norhanani Abd Rahman, Zahriladha Zakaria, Rosemizi Abd Rahim, Yosza Dasril, Amyrul Azuan Mohd Bahar</i> | 1108-1118 |
| Miniaturized Minkowski-Island Fractal Microstrip Antenna Fed by Proximity Coupling for Wireless Fidelity Application | PDF |
| <i>I Putu Elba Duta Nugraha, Indra Surjati, Syah Alam</i> | 1119-1126 |

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JOURNAL CONTENT

Search

Search Scope
All

[Search](#)

Browse

- By Issue
- By Author
- By Title

| | |
|--|---------------------|
| A Mathematical Approach for Hidden Node Problem in Cognitive Radio Networks | PDF |
| <i>Felix Obite, Kamaludin Mohammad Yusof, Jafri Din</i> | 1127-1136 |
| Design and Improvement of a Compact Bandpass Filter using DGS Technique for WLAN and WiMAX Applications | |
| <i>Ahmed Boutejdar, Mohamed Amzi, Saad Dosse Bennani</i> | 1137-1144 |
| A Proposed Design of Unit Cell of Metamaterial for 5G Mobile Communication | |
| <i>Jamal Mohammed Rasool</i> | 1145-1148 |
| New Miniature Planar Microstrip Antenna Using DGS for ISM Applications | PDF |
| <i>R. Er-rebyiy, J. Zbitou, M. Latrach, A. Tajmouati, A. Errkik, L. EL Abdellaoui</i> | 1149-1154 |
| Bandwidth and Gain Enhancement of MIMO Antenna by Using Ring and Circular Parasitic with Air-Gap Microstrip Structure | PDF |
| <i>Teguh Firmansyah, Herudin Herudin, Suhendar Suhendar, Romi Wiryanata, M Iman Santoso, Yus Rama Denny, Toto Supriyanto</i> | 1155-1163 |
| Synchronization Control of Complex Dynamical Networks Based on Uncertain Coupling | |
| <i>Qianqian Jia</i> | 1164-1172 |
| Integral Backstepping Approach for Mobile Robot Control | PDF |
| <i>Bouzgou Kamel, Ibari Benaoumeur, Benchikh Laredj, Ahmed-Foitih Zoubir</i> | 1173-1180 |
| Fuzzy Logic Implementation with MATLAB for PV-Wind Hybrid System | |
| <i>Alias Khamis, Mohd Ruddin Ab. Ghani, Chin Kim Gan, Mohd Shahrieel Mohd Aras, Muhamad Fiqry Khamis, Tole Sutikno, Jano Zanariah</i> | 1181-1191 |
| Estimation of Optimum Number of Poles for Random Signal by Yule-Walker Method | PDF |
| <i>Ahmed Al Amin, Md. Shoriful Islam, K.M. Abdul Al Woadud, Md. Jahirul Islam, Md. Imrul Kayes</i> | 1192-1198 |
| A Review on Methods of Identifying and Counting Aedes Aegypti Larvae using Image Segmentation Technique | PDF |
| <i>Mohamad Aqil Mohd Fuad, Mohd Ruddin Ab Ghani, Rozaimi Ghazali, Mohamad Fani Sulaima, Mohd Hafiz Jali, Tole Sutikno, Tarmizi Ahmad Izzuddin, Zanariah Jano</i> | 1199-1206 |
| Development of Ammonia Gas Leak Detection and Location Method | PDF |
| <i>Ding Xibo, Wang Ru-yue</i> | 1207-1214 |
| Decision Support System for Bat Identification using Random Forest and C5.0 | PDF |
| <i>Deden Sumirat Hidayat, Imas Sukaesih Sitanggang, Gono Semiadi</i> | 1215-1222 |
| Predicting the Presence of Learning Motivation in Electronic Learning: A New Rules to Predict | PDF |
| <i>Christina Juliane, Arry A. Arman, Husni S. Sastramihardja, Iping Supriana</i> | 1223-1229 |
| Improving DNA Barcode-based Fish Identification System on Imbalanced Data using SMOTE | PDF |
| <i>Wisnu Ananta Kusuma, Nurdevi Noviana, Lailan Sahrina Hasibuan, Mala Nurilmala</i> | 1230-1238 |
| A Crop Pests Image Classification Algorithm Based on Deep Convolutional Neural Network | PDF |
| <i>RuJing Wang, Jie Zhang, Wei Dong, Jian Yu, ChengJun Xie, Rui Li, TianJiao Chen, HongBo Chen</i> | 1239-1246 |
| HABCO: A Robust Agent on Hybrid Ant-Bee Colony Optimization | PDF |
| <i>Abba Suganda Girsang, Chun-Wei Tsai, Chu-Sing Yang</i> | 1247-1256 |
| Foreign Tourist Arrivals Forecasting Using Recurrent Neural Network Backpropagation through Time | PDF |
| <i>Wayan Oger Vihikan, I Ketut Gede Darma Putra, I Putu Arya Dharmadi</i> | 1257-1264 |
| Improving Posture Accuracy of Non-Holonomic Mobile Robot System with Variable Universe of Discourse | PDF |
| <i>Siti Nurmaini, Bambang Tutuko, Kemala Dewi, Velia Yuliza, Tresna Dewi</i> | 1265-1279 |
| Feature Extraction of Musical Instrument Tones using FFT and Segment Averaging | PDF |
| <i>Linggo Sumarno, I. Iswanjonno</i> | 1280-1289 |
| Regression Modelling for Precipitation Prediction Using Genetic Algorithms | PDF |
| <i>Asyrofa Rahmi, Wayan Firdaus Mahmudy</i> | 1290-1300 |
| The Addition Symptoms Parameter on Sentiment Analysis to Measure Public Health Concerns | PDF |
| <i>Yohanssen Pratama, Puspoko Ponco Ratno</i> | 1301-1309 |
| A Novel Space-time Discontinuous Galerkin Method for Solving of One-dimensional Electromagnetic Wave Propagations | PDF |
| <i>Pranowo Pranowo</i> | 1310-1316 |
| Binarization of Ancient Document Images based on Multipeak Histogram Assumption | PDF |
| <i>Fitri Arnia, Khairul Munadi</i> | 1317-1327 |
| The Pessimistic Investor Sentiments Indicator in Social Networks | PDF |

| | |
|--|---------------------|
| <i>Rui Jin, Hong-Li Zhang, Xing Wang, Xiao-Meng Wang</i> | 1328-1334 |
| Social Media Success Model for Knowledge Sharing (Scale Development and Validation) | PDF |
| <i>Setiawan Assegaff, Hendri Hendri, Akwan Sunoto, Herti Yani, Desy Kisbiyanti</i> | 1335-1343 |
| A Soft Set-based Co-occurrence for Clustering Web User Transactions | PDF |
| <i>Edi Sutoyo, Iwan Tri Riyadi Yanto, Rd Rohmat Saedudin, Tutut Herawan</i> | 1344-1353 |
| Twitter's Sentiment Analysis on Gsm Services using Multinomial Naive Bayes | PDF |
| <i>Aisah Rini Susanti, Taufik Djatna, Wisnu Ananta Kusuma</i> | 1354-1361 |
| Step-Function Approach for E-Learning Personalization | PDF |
| <i>Sfenrianto Sfenrianto, Zainal A. Hasibuan</i> | 1362-1367 |
| Using SVD and DWT Based Steganography to Enhance the Security of Watermarked Fingerprint Images | PDF |
| <i>Mandy Douglas, Karen Bailey, Mark Leeney, Kevin Curran</i> | 1368-1379 |
| Agent Based Modeling on Dynamic Spreading Dengue Fever Epidemic | PDF |
| <i>Heti Mulyani, Taufik Djatna, Imas Sukaesih Sitanggang</i> | 1380-1388 |
| Managers Perceptions towards the Success of E-performance Reporting System | PDF |
| <i>A'ang Subiyakto, Ditha Septiandani, Evy Nurmiati, Yusuf Durachman, Mira Kartiwi, Abd. Rahman Ahlan</i> | 1389-1396 |
| Histogram Equalization for Improving Quality of Low-resolution Ultrasonography Images | PDF |
| <i>Retno Supriyanti, Subkhi Adhi Priyono, Eko Murdyantoro, Haris Budi Widodo</i> | 1397-1408 |
| Use of Automation Codecs Streaming Video Applications Based on Cloud Computing | PDF |
| <i>Hero Wintolo, Anggraini Kusumaningrum, Handoko Widya Kusuma</i> | 1409-1415 |
| Research and Application of Development Model of Information Service for IOT of Oil and Gas Production Based on Cloud Architecture | PDF |
| <i>Wu Haili, Gong Renbin, Wang Congbin, Gong Lei</i> | 1416-1424 |
| Brown's Weighted Exponential Moving Average Implementation in Forex Forecasting | PDF |
| <i>Seng Hansun, Subanar Subanar</i> | 1425-1432 |
| Miniaturization of Resonator based on Moore Fractal | PDF |
| <i>E. Mohd, S. H. Dahlan</i> | 1433-1439 |
| Effect of Pump Dithering at Each Stage of Cascaded Fiber Optical Parametric Amplifier | PDF |
| <i>Fatin Nabilah Mohamad Salleh, Nor Shahida Mohd Shah, Nurulanati Othman, Rahmat Talib, Munirah Ab. Rahman</i> | 1440-1445 |
| An Upgraded Transverse Electromagnetic Parallel Plates for Dielectric Measurement | PDF |
| <i>S. K. Yee, R. Padu, C. K. Sia, X. T. I. Ngu, S. H. Dahlan, M. A. Azlan</i> | 1446-1453 |
| Flexible Wearable Antenna on Electromagnetic Band Gap using PDMS substrate | PDF |
| <i>Adel Y. I. Ashap, Z. Z. Abidin, S. H. Dahlan, H. A. Majid, S. K. Yee, Gameel Saleh, Norun Abdul Malek</i> | 1454-1460 |
| Numerical Simulation of Highly-Nonlinear Dispersion-Shifted Fiber Optical Parametric Gain Spectrum with Fiber Loss and Higher-Order Dispersion Coefficients | PDF |
| <i>K. G. Tay, N. Othman, N. S. M. Shah, N. A. Cholan</i> | 1461-1469 |
| Microstrip to Parallel-Strip Nonlinear Transition Balun with Stubs and DGS for UWB Dipole Antenna | PDF |
| <i>S. A. Hamzah, S. Mohd Shah, H. Majid, K. N. Ramli, M. S. Zainal, L. Audah, S. Z. Sapuan, A. Ubin, M. Esa, N. N. Nik Abd Malik</i> | 1470-1476 |
| Enhanced Payload Data Reduction Approach for Cluster Head (CH) Nodes | PDF |
| <i>N. A. M. Alduais, J. Abdullah, A. Jamil</i> | 1477-1484 |
| Integrated Open Loop Resonator Filter Designed with Notch Patch Antenna for Microwave Applications | PDF |
| <i>D. Azra Awang Mat, N. Syuhada Hasim, Nurmiiza Othman, Amira Amran, D. Norkhairunnisa Abang Zaidel, A. S. Wani Marzuki, Shafrida Sahrani, Kismet anak Hong Ping, Rohana Sapawi</i> | 1485-1492 |

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Bandwidth and Gain Enhancement of MIMO Antenna by Using Ring and Circular Parasitic with Air-Gap Microstrip Structure

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Abstract

This research was proposed a circular patch MIMO antenna by using a ring and circular parasitic radiator structure. As a novelty, in order to enhance bandwidth and gain of circular patch MIMO antenna, a conventional circular patch MIMO antenna will be added a ring and a circular parasitic. Therefore, this research was investigated a conventional MIMO antenna (C-MA), ring parasitic MIMO antenna (RP-MA), and circular parasitic MIMO antenna (CP-MA) as Model 1, Model 2, and Model 3, respectively. This MIMO antenna was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, thickness $h = 1.6$ mm, and $\tan \delta = 0.0265$. This MIMO antenna has center frequency 2.35 GHz which is a frequency band for LTE application in Indonesia. An Advance Design System (ADS) software was used to determine the antenna parameters. The MIMO antenna C-MA / RP-MA/ CP-MA achieves 2.36GHz/ 2.38GHz/ 2.38 GHz, 70 MHz/ 100 MHz/ 120 MHz, 1.625 dBi/ 4.066 dBi/ 4.117 dBi, 6.414 dBi/ 7.26 dBi/ 7.153 dBi, 33.9 %/ 47.8 %/ 49.70 %, -12.35 dB/ -22.21 dB/ -23.66 dB, and -30.924 dB/ -28.46 dB/ -27.59 dB for center frequency, bandwidth, gain, directivity, efficiency, reflection coefficient, and mutual coupling, respectively. Compared to C-MA (Model 1) performances, The result showed that proposed antenna has wider-bandwidth/ higher-gain with 42.8%/ 150.2 %, and 71.4%/ 163.3% for RP-MA (Model 2) and CP-MA (Model 3), respectively. The proposed antenna has size of 50 mm x 130 mm x 23.2 mm. Measured results are in a good agreement with the simulated results.

Keywords: Antenna, MIMO, ring parasitic, circular parasitic

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1. Introduction

A Long Term Evolution (LTE) technology was developed to provide the requirement of wireless data access with high bit-rate [1, 2]. The LTE technology uses a Multiple Input Multiple Output (MIMO) antenna system [3-5]. Antennas based on microstrip technology are popularly used because it has many benefits such as low cost, low profile, ease fabrication, and compact [6, 7]. However, the microstrip antenna has disadvantages such as narrow bandwidth and low gain [8, 9]. There are some attractive methods frequently used to enhance bandwidth and gain such as microstrip-slot [10-12], microstrip notch [13], and parasitic air gap [14-19]. The research which proposed by [10], [12-13] increases the bandwidth of the antenna, without gain enhancement. Some antenna mentioned above still a relatively complex geometry. A parasitic gap method which proposed by [14-19] are an excellent method. That method was not only to increase bandwidth but also enhance a gain. Unfortunately, these studies are only applied to a single patch antenna, not a MIMO antenna. MIMO antenna system is considered not only a bandwidth, and a gain but also a mutual coupling. A frequently used method to reduce a mutual coupling such as defected ground structure (DGS) [20], Electromagnetic band gap (EBG) [21], and Metamaterial mushroom structures. These methods made more complicated designs of MIMO antenna.

As a novelty, this research proposed a circular patch MIMO. In order to enhance bandwidth and gain, a conventional circular patch MIMO antenna will be added a ring and a circular parasitic radiator structure. Therefore, generally this research was investigated a conventional MIMO antenna (C-MA), ring parasitic MIMO antenna (RP-MA), and circular

parasitic MIMO antenna (CP-MA) as Model 1, Model 2, and Model 3, respectively. This MIMO antenna was designed on FR4 microstrip substrate with $\epsilon_r= 4.4$, thickness $h=1.6$ mm, and $\tan \delta= 0.0265$. This MIMO antenna has center frequency of 2.35 GHz, which is a frequency band for LTE application in Indonesia. A performance of MIMO antenna will be investigated include center frequency, bandwidth, gain, directivity, efficiency, reflection coefficient, and mutual coupling. The design of methodology was detailed in the following sections. Section 2 describes the design of a circular patch MIMO antenna by using a ring and circular parasitic radiator structure. The simulation was described in Section 3, and the measurement results of the MIMO antenna was described in Section 4. Finally, Section 4 concludes this research.

2. Research Method

This part discusses some methods to conduct the research. Figure 1(a) shows a circular patch conventional MIMO antenna (C-MA) [Model 1]. Figure 1(b) shows circular patch MIMO antenna with a ring-parasitic substrate (RP-MA) [Model 2]. Furthermore, Figure 1(c) shows circular patch MIMO antenna with a circular-parasitic substrate (CP-MA) [Model 3].

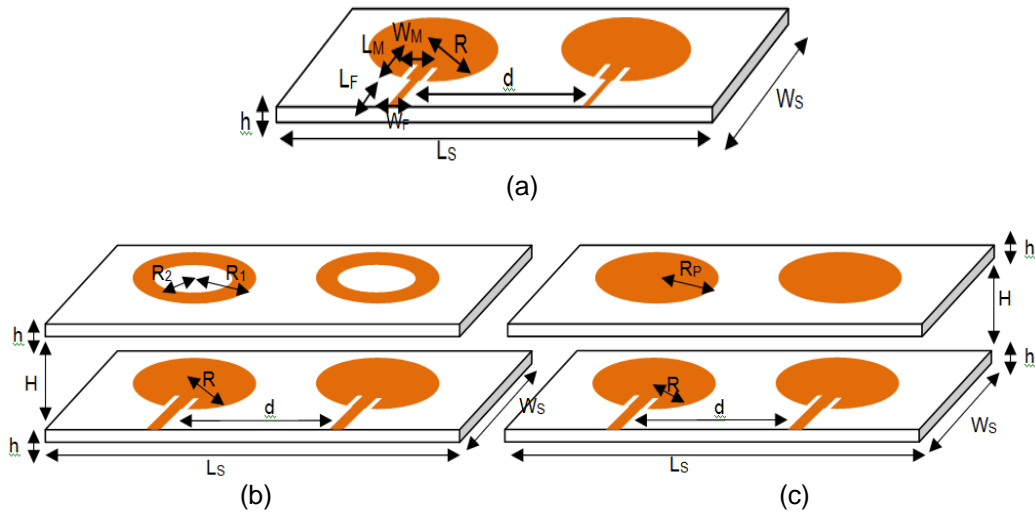


Figure 1. (a) Conventional MIMO antenna (C-MA) [Model 1], (b) MIMO antenna with ring parasitic substrate (RP-MA) [Model 2], (c) MIMO antenna with circular parasitic substrate (CP-MA) [Model 3]

The radius of circular patch microstrip antenna is given by [22]:

$$R = \frac{F}{\sqrt{1 + \frac{2h}{\pi\epsilon_r} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726 \right]}} \tag{1}$$

Where,

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \tag{2}$$

With h = thickness of substrate (cm) and f_r = resonant frequency (Hz).

In this research, a direct feeding method was used. The relationship between width-thickness (W/h) ratio of the feeding size and the value of Z_0 and the constant dielectric ϵ_r can be obtained by Equation (3) [23-25]:

$$\frac{W}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2} & \text{for, } (W/h < 2) \\ \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B - 1) + 0,39 - \frac{0,61}{\epsilon_r} \right\} \right] & \text{for, } (W/h > 2) \end{cases} \quad (3)$$

Where:

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left\{ 0,23 + \frac{0,11}{\epsilon_r} \right\} \quad (4)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \quad (5)$$

Furthermore, the Z_0 can be determined by the ratio of width and thickness (W/h) [23-27]:

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) & \text{for } (W/h \leq 1) \\ \frac{120\pi}{\sqrt{\epsilon_e} \left[\frac{W}{h} + 1,393 + 0,667 \ln\left(\frac{W}{h} + 1,444\right) \right]} & \text{for } (W/h \geq 1) \end{cases} \quad (6)$$

where:

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12h/W}} \quad (7)$$

This MIMO antenna was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, thickness $h = 1.6$ mm, and $\tan \delta = 0.0265$. An Advance Design System (ADS) software was used to determine the antenna parameters. Figure 2(a) shows the extracted reflection coefficient and mutual coupling values with varied R_2 . The chart shows that the reflection coefficient can be tuned by modifying R_2 . It also can be seen that the mutual coupling values are still below -20 dB for all values of R_2 . Furthermore, Figure 2(b) shows the extracted reflection coefficient and mutual coupling values with varied R_p . It shows that R_p only significant affect to reflection coefficient, with less effect on mutual coupling.

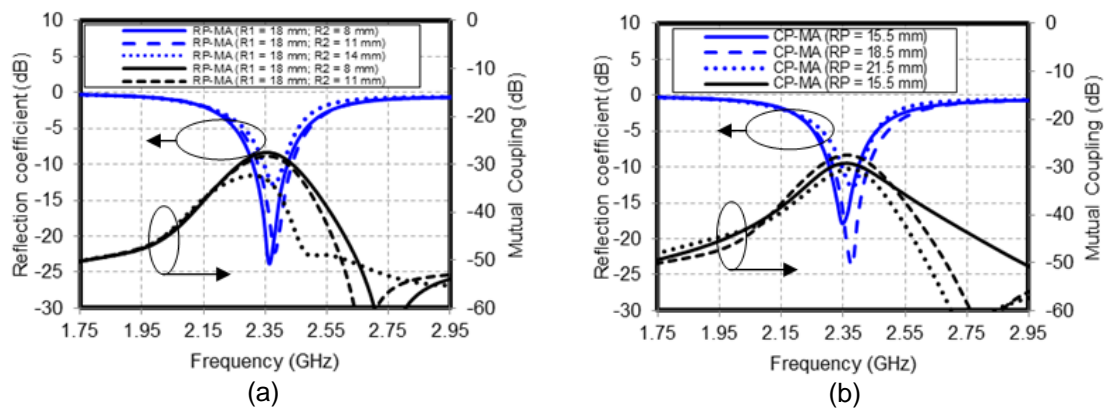


Figure 2. (a) The extracted reflection coefficient and mutual coupling values with varied R_2 ; (b) The extracted reflection coefficient and mutual coupling values with varied R_p

Figure 3(a) shows the extracted reflection coefficient with different distance between antennas d (mm). The chart reveals that the value of reflection coefficient at the center frequency lower than -10 dB. This result indicates that the distance d (mm) does not influence the center frequency. Figure 3(b) shows that the extracted mutual coupling with varied d (mm). These results determine that the smaller the antenna distance would be higher the coupling value.

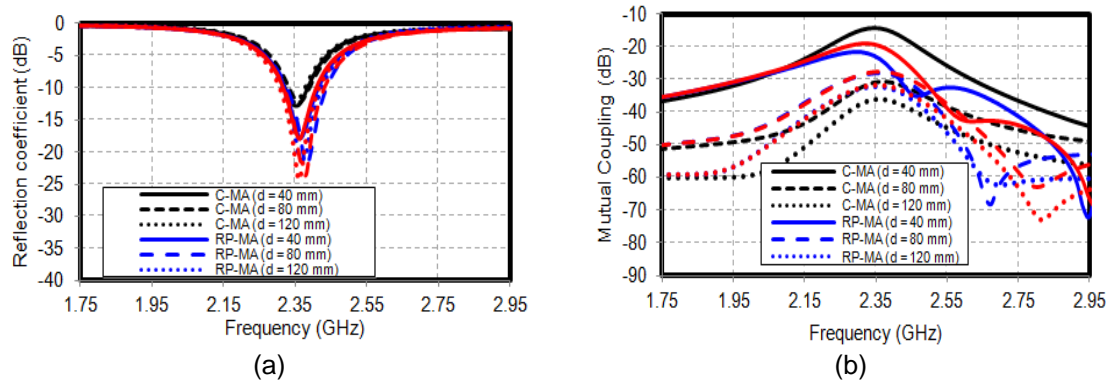


Figure 3. (a) The extracted reflection coefficient with varied distance d (mm); (b) The extracted mutual coupling with varied distance d (mm).

Figure 4(a) shows the extracted reflection coefficient with a variable distance between antennas and radiator H (mm). These results show that the various distance (H) will shift a center frequency. Moreover, the reflection coefficient at the center frequency is still lower than -10 dB. Otherwise, Figure 4(b) illustrated the mutual extraction coupling with different distance between antennas and radiator H (mm). The H is varied from 10 mm to 30 mm. It shows that the variation of H affected to mutual coupling values but still good isolation.

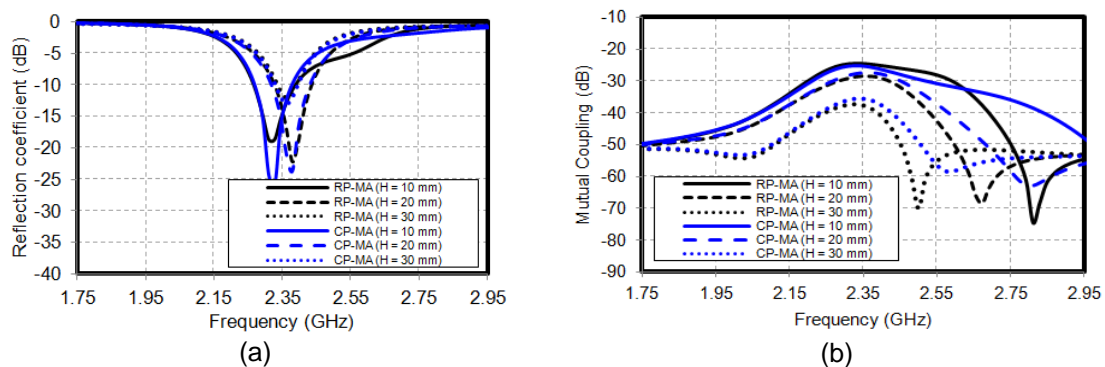


Figure 4. (a) The extracted reflection coefficient with varied distance H (mm); (b) The extracted mutual coupling with varied distance H (mm)

3. Results and Analysis

We organize the circular patch MIMO antenna by using a ring and circular parasitic radiator by special structure as depicted by Figure 1. The size of MIMO antenna are $L_S = 130$ mm, $W_S = 50$ mm, $L_F = 7.1$ mm, $W_F = 3$ mm, $L_M = 7.9$ mm, $W_M = 1$ mm, $R = 18.5$ mm, $h = 1.6$ mm, $d = 80$ mm, $R_1 = 18$ mm, $R_2 = 11$ mm, $H = 20$ mm, $R_P = 18.5$ mm. This MIMO antenna was designed on FR4 microstrip substrate with $\epsilon_r = 4.4$, thickness $h = 1.6$ mm, and $\tan \delta = 0.0265$. An Advance Design System (ADS) software was used to determine the antenna parameters. Vector Network Analyzer Agilent N9913A-210 was used to test an antenna performances. Furthermore, the photograph of fabricated antenna was shown in Figure 5.

Figure 6(a) and Figure 6(b) shows a comparison between simulated and measured of reflection coefficient and mutual coupling of circular patch MIMO antenna by using a ring and circular parasitic radiator structure. The C-MA antenna [Model-1] achieves center frequency = 2.36 GHz, bandwidth = 70 MHz, reflection coefficient = -12.35 dB, mutual coupling = -30.92 dB. The RP-MA antenna [Model-2] achieves simulated/measured of center frequency = 2.38 GHz/2.36 GHz, bandwidth = 100 MHz/100 MHz, reflection coefficient = -22.21 dB/ -15.93 dB, mutual coupling = -28.46 dB/-28.83 dB. The CP-MA antenna [Model-3] achieves

simulated/measured of center frequency = 2.38 GHz/2.36 GHz, bandwidth = 120 MHz/110 MHz, reflection coefficient = -23.66 dB/ -24.89 dB, mutual coupling = -27.59 dB/-31.67 dB. A good agreement can be observed between the simulated and measured results, which demonstrates the validity of the design.

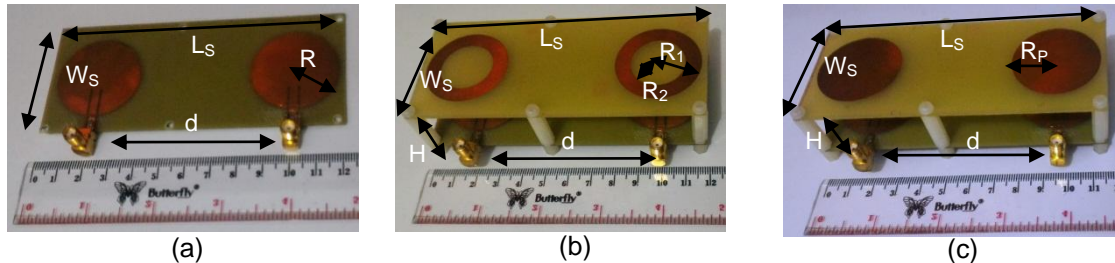


Figure 5. (a) Photograph of conventional MIMO antenna (C-MA) [Model 1], (b) Photograph of MIMO antenna with ring parasitic substrate (RP-MA) [Model 2], (c) Photograph of MIMO antenna with circular parasitic substrate (CP-MA) [Model 3]

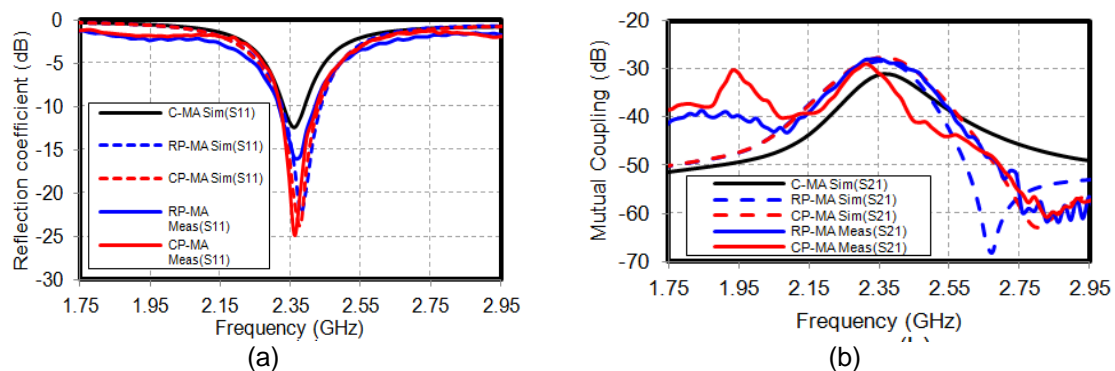


Figure 6. (a) The comparison between simulated and measured of reflection coefficient; (b) The comparison between simulated and measured of mutual coupling

Figure 7(a) shows the extracted gain and reflection coefficient with varied distance H (mm). In this research, the distance $H = 20$ mm was used which produce high gain with good reflection coefficient, simultaneously. Figure 7(b) shows that MIMO antenna with additional a ring and a circular parasitic radiator structure has higher gain compare to conventional MIMO antenna. Figure 7(c) and Figure 7(d) show a directivity and efficiency, respectively. The charts show that a directivity and efficiency of MIMO antenna with a ring and a circular parasitic radiator structure has higher value compare to conventional MIMO antenna.

Figure 8(a) displays the surface current distribution of circular antenna. The surface current distribution flowed only at the circular patch. Furthermore, Figure 8(b) shows the surface current distribution of circular antenna with parasitic ring substrate. The surface current distribution flowed not only at the circular patch but also at parasitic ring substrate. Moreover, Figure 8(c) shows the surface current distribution of circular antenna with circular parasitic substrate. The surface current distribution was flowed not only at the circular patch but also at circular parasitic substrate.

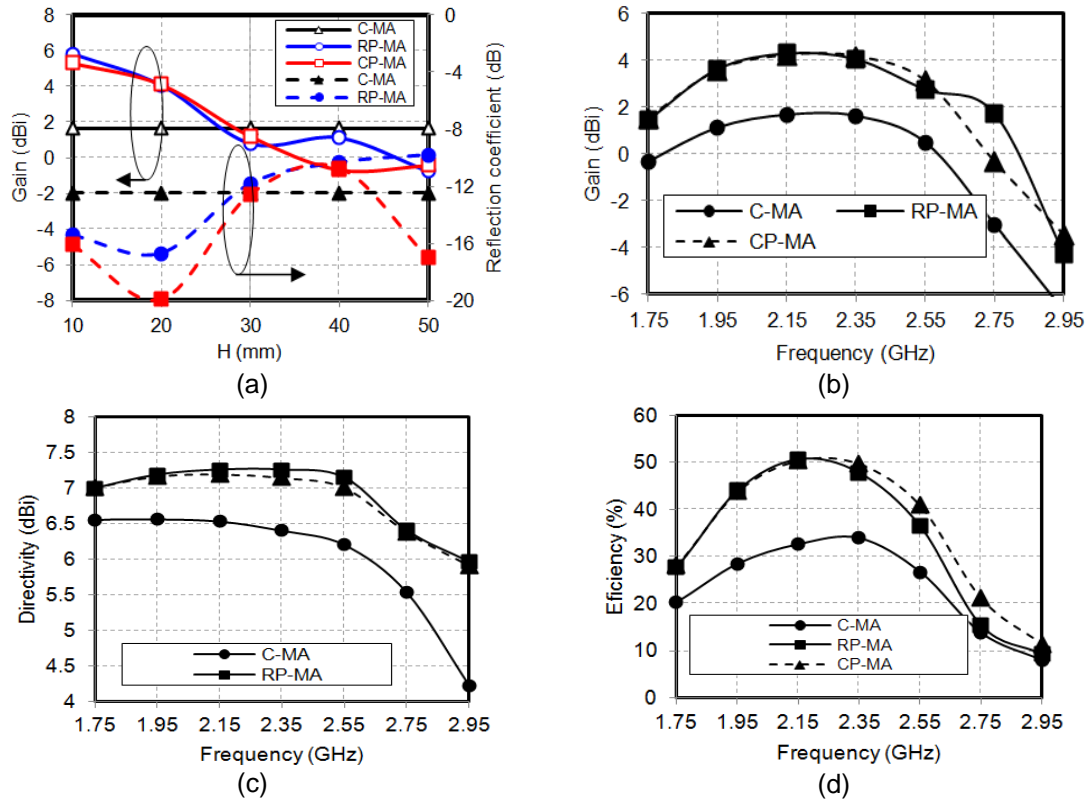


Figure 7. (a) The extracted gain and reflection coefficient with varied distance H (mm), (b) The comparison of gain (dBi), (c) The comparison of directivity (dBi), (d) The comparison of efficiency (%)

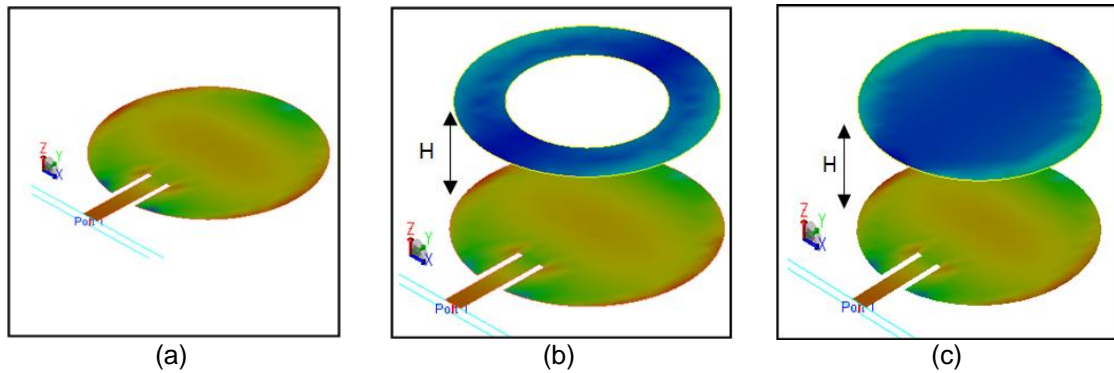


Figure 8. (a) The surface current distribution of circular antenna, (b) The surface current distribution of circular antenna with ring parasitic substrate, (c) The surface current distribution of circular antenna with circular parasitic substrate

Figure 9(a), Figure 9(b), and Figure 9(c) expose radiation pattern of conventional MIMO antenna (C-MA) [Model 1], MIMO antenna with ring parasitic substrate (RP-MA) [Model 2] and MIMO antenna with circular parasitic substrate (CP-MA) [Model 3].

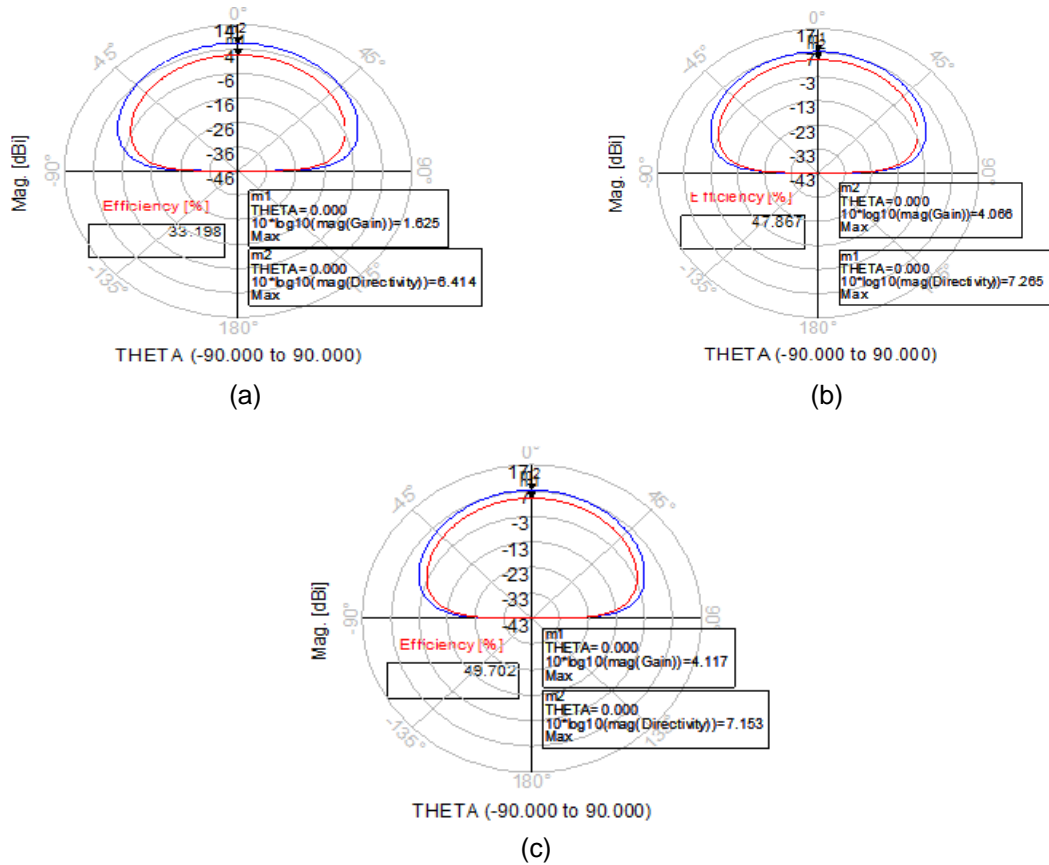


Figure 9. (a) Radiation pattern of conventional MIMO antenna (C-MA) [Model 1], (b) Photograph of MIMO antenna with ring parasitic substrate (RP-MA) [Model 2], (c) Radiation pattern of MIMO antenna with circular parasitic substrate (CP-MA) [Model 3]

Table 1 summarizes the comparison of conventional MIMO antenna (C-MA) [Model 1], MIMO antenna with ring parasitic substrate (RP-MA) [Model 2], and MIMO antenna with circular parasitic substrate (CP-MA) [Model 3].

Table 1. Comparison of C-MA Antenna, RP-MA Antenna and CP-MA performances

| Variables | C-MA | RP-MA | | CP-MA | |
|-----------------------------|-----------|-----------|-----------|-----------|-----------|
| | [Model 1] | [Model 2] | [Model 2] | [Model 3] | [Model 3] |
| | Simulated | Simulated | Measured | Simulated | Measured |
| Center Frequency (GHz) | 2.36 | 2.38 | 2.36 | 2.38 | 2.36 |
| Bandwidth (MHz) | 70 | 100 | 100 | 120 | 110 |
| Gain (dBi) | 1.625 | 4.066 | NA | 4.117 | NA |
| Directivity (dBi) | 6.414 | 7.265 | NA | 7.153 | NA |
| Efficiency (%) | 33.9 | 47.8 | NA | 49.70 | NA |
| Reflection coefficient (dB) | -12.35 | -22.21 | -15.93 | -23.66 | -24.89 |
| Mutual coupling (dB) | -30.924 | -28.46 | -28.83 | -27.59 | -31.67 |
| Size | W (mm) | 50 | 50 | 50 | 50 |
| | L (mm) | 130 | 130 | 130 | 130 |
| | H (mm) | 1.6 | 23.2 | 23.2 | 23.2 |

4. Conclusion

A novel configuration of circular patch MIMO antenna using a ring and circular parasitic radiator structure have been simulated, fabricated, and measured. The C-MA antenna [Model-1] achieves center frequency = 2.36 GHz, bandwidth = 70 MHz, reflection coefficient = -12.35 dB, mutual coupling = -30.92 dB. The RP-MA antenna [Model-2] achieves simulated/measured of center frequency = 2.38 GHz/2.36 GHz, bandwidth = 100 MHz/100 MHz, reflection coefficient =

-22.21 dB/ -15.93 dB, mutual coupling = -28.46 dB/-28.83 dB. The CP-MA antenna [Model-3] achieves simulated/measured of center frequency = 2.38 GHz/2.36 GHz, bandwidth = 120 MHz/110 MHz, reflection coefficient = -23.66 dB/ -24.89 dB, mutual coupling = -27.59 dB/-31.67 dB. A good agreement can be observed between the simulated and measured results, which demonstrates the validity of the design. This result also validates that the addition circular patch MIMO antenna with a ring and circular parasitic radiator structure MIMO could increase bandwidth and gain of MIMO antenna simultaneously. Thus, the proposed MIMO antenna is suitable for LTE application in Indonesia.

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