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Optimization of Planar Radiator with Slot and Shorting Pin for Pattern Reconfigurable Antenna

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Abstract

Another design of the pattern reconfigurable antenna has been proposed. The antenna is formed using a circular planar antenna base structure where the antenna is feed by coaxial probe. For matching impedance purpose, two elements namely shorting pin and slot are attached close together to feeding point. At the edge of the radiator, 24 edge shorting pins were installed intended to adjust the antenna radiation pattern. In designing this antenna, Genetic algorithms (GA) are used to optimize three variables that greatly affect operating frequency, return loss and antenna radiation pattern that are radius of radiator, length of slot, and state of 24 edge shorting pins. This procedure produces antenna design that is directed towards 45o in the elevation plane and can be switched across all direction in the azimuth plane. Optimization, simulation, and measurement data are presented completely for validation purposes.

Keywords; *Pattern Reconfigurable Antenna, Planar Structure, Genetic Algorithm, Shorting pin, Slot*

I. INTRODUCTION

Reconfigurable antenna is one of the interesting topics in the development and study of antennas in the past few years because of its multifunctional capabilities and adaptability that are needed for nowadays and future modern wireless communication. Multifunctional capabilities include multi-frequency (frequency reconfigurability), multi-beam (pattern reconfigurability), and multi-polarization (polarization reconfigurability). A reconfigurable antenna can only have single reconfigurable feature such as frequency reconfigurable or can also have multiple reconfigurable capabilities which are a combination of two or three functions such as pattern reconfigurable and polarization reconfigurable [1][2].

Pattern Reconfigurable antenna which is one type of reconfigurable antenna offers several critical advantages for wireless communication such as increasing system gain, saving energy, avoid the adverse effects of a noisy and disturbing channel environment and also dodge from interference and jamming source for security [3]. For WLAN applications, for example [4], the pattern reconfigurable antenna is very useful for improving Signal to Noise ratio (SNR) by directing the antenna main beam towards the user who needs it and avoids it towards the interference source. Increasing SNR will greatly help improve communication performance including increasing data rate. For Wireless Sensor Network (WSN) applications, the pattern reconfigurable antenna is very important because of the limited energy source of the sensor. By replacing an omnidirectional radiation pattern antenna with a pattern reconfigurable antenna, in general the WSN system will be better in several terms including addition to energy savings, improving receiver sensitivity, and extending the propagation distance between nodes [5]. For the 5th generation communication system (5G) which is

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currently being developed for future communication systems, according to leaked information, this system will rely heavily on cognitive radio. Cognitive radio basically works by sensing all changes in wireless environment and then adapting all system parameters to get the most optimal performance. This shows that the cognitive radio is a very adaptive system wherein it will require reconfigurable capabilities including the pattern reconfigurable antenna [6].

Basically, the pattern reconfigurable antenna is needed for applications that require a beam forming / beam steering capability such as surveillance and tracking [2]. To make these capabilities usually antenna arrays are often used. However because antenna arrays have shortcomings in their large size and relatively has complex feeding systems, the pattern reconfigurable antenna can be an alternative. Some techniques that can be used to get the ability of the pattern re-configurability include mechanical controlling methods, electrical methods, changing the material method, and metamaterial method [7]. Several studies related to the pattern reconfigurable antenna design have been carried out [8][9][10][11].

In terms of structure design, some of the pattern reconfigurable antennas have a non-simple design. Need more effort from researchers to design these antennas. Some researchers use optimization algorithms to assist in designing procedure. One of the optimization algorithms that have been widely used in antenna design is genetic algorithms. Research on the use of genetic algorithms in antenna design has also been carried out [12][13][14][15].

In this study the author continued the research that had previously been done, namely optimizing a circular planar antenna structure using a GA and Finite Element Method (FEM) base simulator where the design of the antenna can be used as a pattern reconfigurable antenna.

II. ANTENNA STRUCTURE

In this study the author still maintains a circular shape of radiator to accommodate symmetrical structure properties. the feed probe is positioned almost in the center of the radiator even though it is not precisely at there and maintened in its position. Then a slot with a certain length and width is located in the middle of the radiator and separates the feed probe from a control shorting pin. The main function of the control shorting pin and slot is for matching impedance purpose.

The characteristics and analysis of patch circular antennas with a control pin and slot can be seen in [16], readers who interest in detail can read the article. The circular patch antenna structure with a control pin and slot that has been integrated with the edge shorting pin can be seen in **Fig.1**

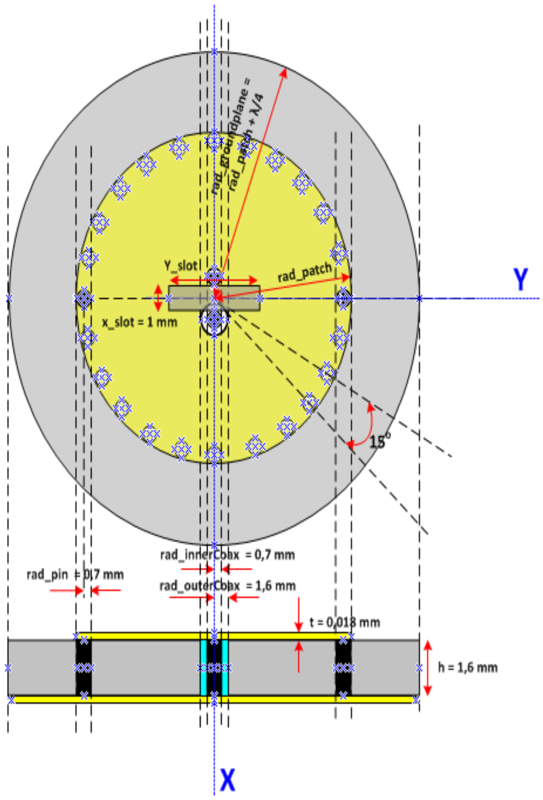

Fig.1. Antenna Structure

Complete optimum antenna parameters without edge shorting pins are shown in **Table 1**

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Table 1. Antenna parameters

Structure Parameters	Symbol	Value (in mm)
Radius of radiator	Rad_patch	81,2 (will be further optimized)
Radius of Control shorting pin	rad_pin	0,7
Slot width	X_*slot*	1
Slot length	Y_slot	1 (will be further optimized)
Strip Conductor Thickness	t	0,018
Substrate Thickness	h	1,6
Radius of Inner Coaxial (probe)	rad_innerCoax	0,7
Radius of Outer Coaxial	rad_outerCoax	1,6

III. OPTIMIZATION PROCESS

In this section, optimization process using FEM and genetic algorithms on antenna structure will be explained.

A. General procedure

In general, this optimization process aims to obtain an antenna design with radiation pattern characteristics that are meet the desired target. The target is an unidirectional radiation pattern with an arbitrary direction of the azimuth plane but 45^o of the elevation plane. The target certainly has the consequence of changing the antenna operating frequency and matching impedance conditions which are expected to remain in the 2.4 GHz and return loss less than -10 dB.

To accommodate these conditions, three antenna variables will be optimized. The first variable is the state of edge shorting pin. Optimization of this variable is done by assigning whether active or not the shorting pin on the edge of the radiator. Active state indicates there is connection between the radiator and ground plane. Inactive state indicates no connection between the radiator and ground plane. This variable optimization is intended to adjust the antenna radiation pattern. The second variable is the radiator radius. This variable optimization is done by assigning the appropriate value of the radius of the radiator. Radiator radius is a variable that greatly determines the antenna operating frequency. The last variable is the length of the slot. By setting the proper slot length, then the impedance mismatch can be controlled.

When all three variables reach their optimum value, an antenna design that works at a frequency of 2.4 GHz with a certain azimuth field pattern and a 45^o elevation field pattern will be obtained. Then for the reconfigurable pattern purpose, the shorting pin state can be changed by specifying a specific reference point on a shorting pin and then maintaining a combination of state condition of all edge shorting pin.

B. FEM and GA Integration

Basically, the antenna optimization process involves two software that is Matlab and HFSS (High Frequency Structure Simulator) as shown in the figure **Fig.2**. Genetic algorithms will be implemented in Matlab codes. While for fitness function evaluation that involves several antenna parameters i.e. Directivity and return loss, a structure simulator is needed to predict these parameter values, in this study the author uses HFSS which is a 3D full wave numerical method electromagnetic simulator based on Finite Element Method (FEM).

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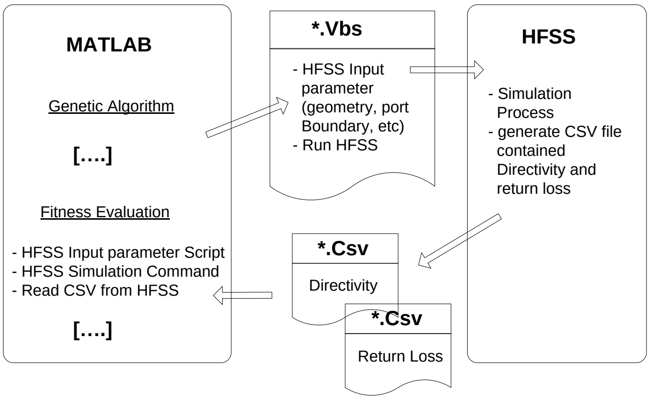

Fig.2. FEM and AG Integration

Simulations are automatically controlled by the genetic algorithm in Matlab and the information exchange between two software is done using VBS (Visual Basic Script) and CSV (Comma-Separated Values).

The VBS script that contains codes is used to produce an antenna structure that will be simulated in HFSS includes all necessary information such as geometry, port, boundary, simulation setup, and parameters to be exported. After the simulation in HFSS is complete, then the CSV file containing antenna parameters information (directivity and return loss) is generated by HFSS, and then read by Matlab for fitness evaluation.

C. GA Process

In this section three main processes of genetic algorithms as shown in **Fig.3**, namely initiation, Reproduction cycle, and population generation will be explained.

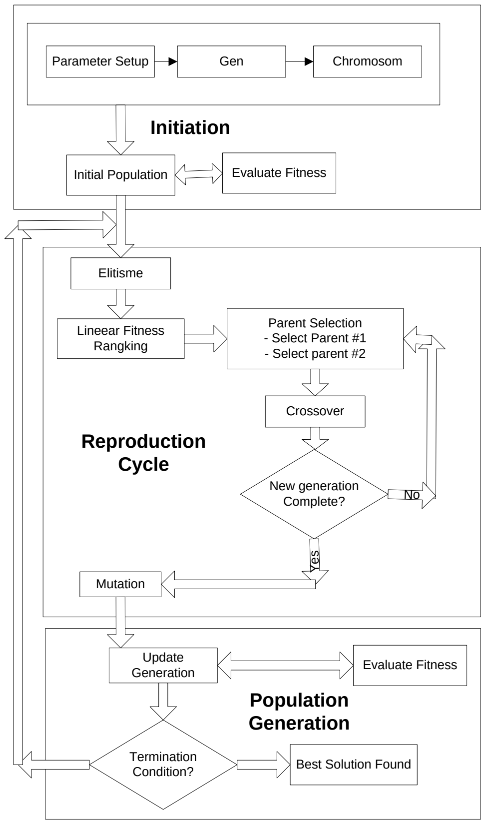

Fig.3. GA Process

1) Initiation

In this phase, optimization problems are initialized. The main antenna optimization problem is expressed in the AG environment.

as mentioned in section A, that there are 3 antenna variables to be optimized, namely 24 edge shorting pin state, radiator radius, and gap length. These three variables are represented using a collection of binary bits and then arranged in a certain sequence and then called chromosomes.

To express these three variables in the AG environment, Total 24 binary bits are used. 24 binary bits are represent edge shorting pin state variable, the bit 1 represents the active state, while the bit 0 represents the inactive state. Than these 24 binary bits followed by next 10 bits that represent the radiator radius value, and than the last 10 bits represent the slot length value. This chromosome illustration can be seen in **Fig.4**

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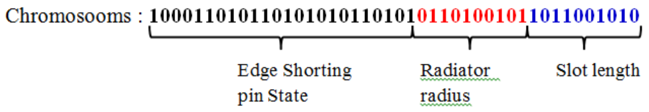

Fig.4. Chromosome Formation

In the AG environment, chromosomes are randomly generated as much as population size to form the initials population. Illustration of initial population formation can be seen in **Fig.5**

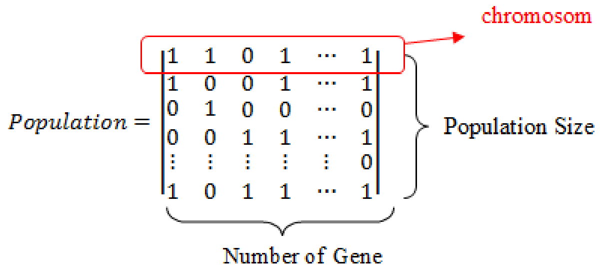

Fig.5. Initial Population Formation

After the population is generated then a fitness evaluation is carried out. The fitness function used can be seen in equation 1. The fitness function will point the main beam of radiation pattern towards the target and simultaneously maintain the operating frequency with the smallest possible return loss.

$$Fitness = 4 \times Directivity(\theta, \phi) + \left| S_{11(dB)}(f) \right| \qquad (1)$$

2) Reproduction Cycle

In this phase, primary processes of AG are processed such as, Elitism, Linear Fitness ranking, parent selection, crossovers, and mutations. These processes that will become the forerunner to the formation of a new generation.

Elitism is a strategy so that individuals / chromosomes that have the highest fitness value for each generation are not lost due to selection, cross over, or mutation. So this chromosome must be preserved / duplicated. Procedure for elitism process shown in **Fig.6**

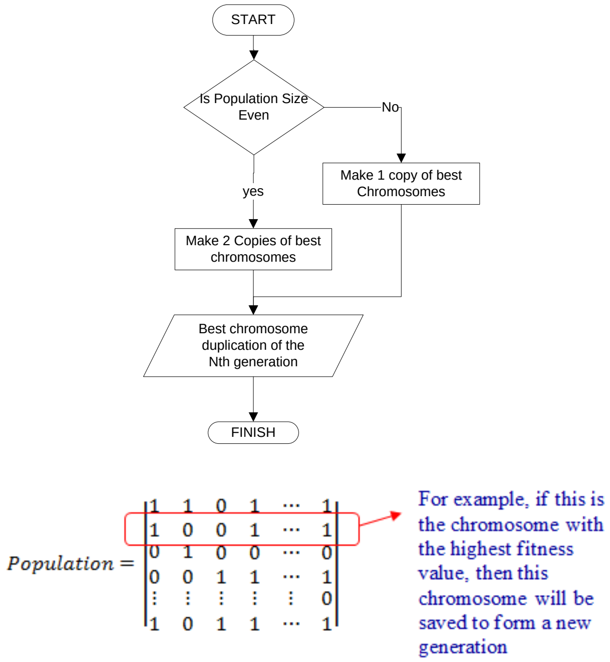

Fig.6. Elitism Process

The next process is Liner Fitness Ranking (LFR). This process is used to scale fitness values that have been obtained in order to reduce the tendency of optimization converge to the local optimum. To make a linear fitness ranking, equation 2 can be used.

$$LFR(i) = Fitness_{\max} - \left(Fitness_{\max} - Fitness_{\min}\right)\left(\frac{R(i)-1}{N-1}\right) \qquad (2)$$

Where, R(i) is nth individual ranking and N is population size.

Parent selection process is done to get a good prospective parent, where "a good parent will produce good offspring". The higher the fitness value of an individual the more likely it is to be chosen as a parent. One selection technique is to use is the Roulette-wheel technique.

This technique imitates the Roulette-wheel game in which each chromosome occupies a circle piece on the roulette wheel proportionally according to its fitness value. Chromosomes with greater fitness values will occupy a larger circle of chunks compared to chromosomes with lower fitness values. This illustrates in **Fig.7**

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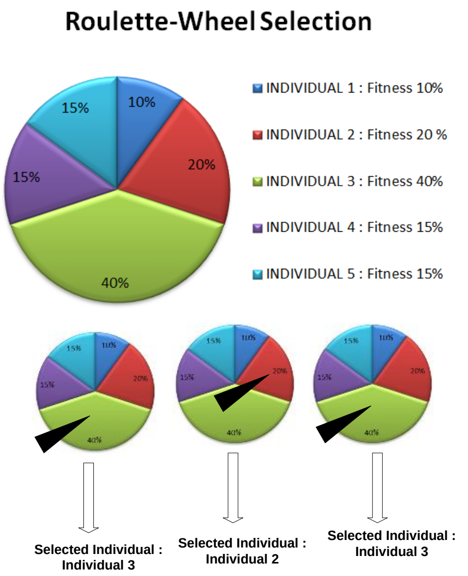

Fig.7. Roulette-Wheel Selection

Crossover is done by exchanging genes from two parents randomly. This process occurs if a random number generated has a value less than the probability of a crossover. There are several techniques for doing cross over, one of which is single point cross over. This process illustrated in **Fig.8**

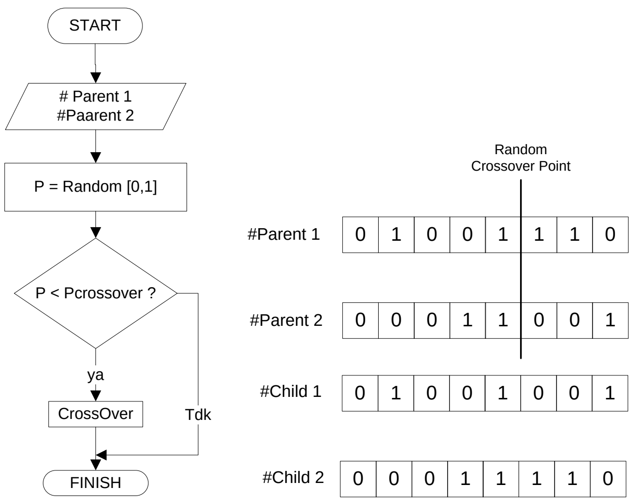

Fig.8. One Point Crossover

From the elitism, parent selection, and crossover processes, new generations are formed. These processes are carried out randomly, but the optimization process itself is not completely random because the formation of this new generation will produce better individuals and certainly will produce higher fitness.

Gene mutation is an operator that exchanges the value of a gene with its inverse value, for example its gene is 0 to 1 or vice versa. Mutations have the chance to occur for each gene on a chromosome or occur randomly. Mutations occur if a randomly generated number is smaller than the probability of its mutation (P mutation). The illustration of mutation process is shown in **Fig.9**

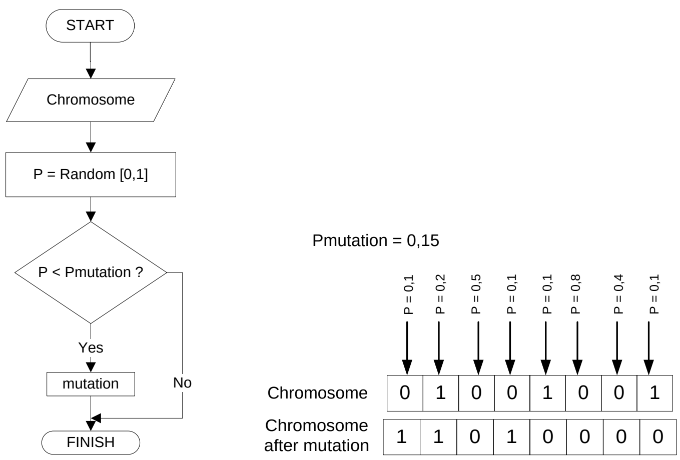

Fig.9. Mutation Process

3) Population Generation

In this phase, all individuals in the population of a particular generation are replaced with a new generation andthen the fitness value is recalculated.

IV. RESULT AND DISCUSSION

In this section, Simulation and measurement result will be presented. In the last part of this section the mechanism for utilizing the optimization results of this study to be used as a pattern reconfigurable antenna will be explained.

A. Optimization, Simulation, and Measurement Result

The simulation and optimization results on 3 variables with the range as shown in Table 2 using AG parameters setup as shown in **Table3** have converged when they reach the 6th generation, meaning that after that generation, there will be no

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improvement in fitness value. As shown in **Fig.10** The optimum simulation results are achieved when the fitness value reaches 31.79

Table 2. Variable range

Variable	**Range**
y_slot	4 mm s/d 10 mm
rad_patch	20 mm s/d 25 mm
Edge Shorting Pin State	Initial State : 10 randomly active state at 24 shorting pin

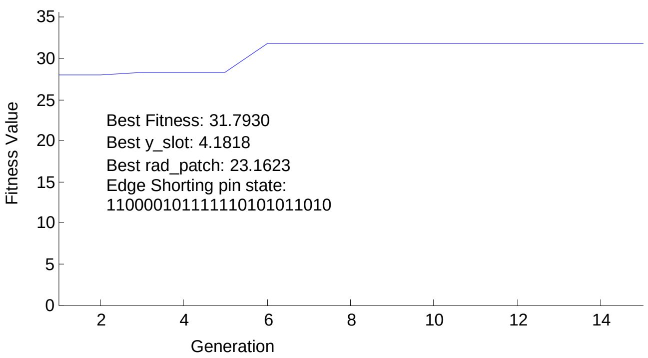

Fig.10. Fitness Evaluation

Table3. GA parameter Setup

GA parameter	**Setup**
Population Size	50
Chromosome	one Chromosome = 44 bit biner
Gene	gene 1 : edge shorting pin state (24 bit), gene 2 : Rad_1 (10 bit), gene 3 : W_slit (10 bit)
Crossover	One–point Crossover with crossover probability = 0,875
Mutation	All bits on the chromosome have the possibility of mutations with the mutation probability = 0,01
Parent Selection procedure	Roulette Wheel Selection
Number of Generation	15

Antenna characteristics using optimum variables on simulation can be seen in **Fig.11**. It can be seen that the main beam of antenna elevation pattern close to 45°, while the resonance frequency is at 2.4 GHz with a minimum return loss of -41 , 82 dB, maximum directivity 3.4 dB and bandwidth 36 MHz (1.25%).

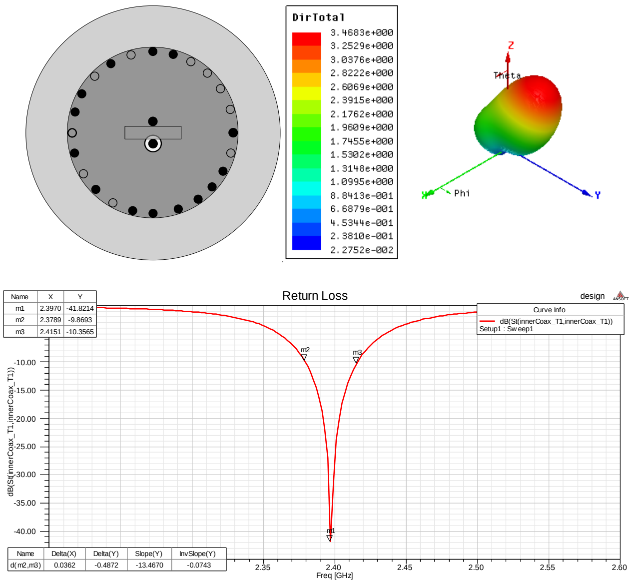

Fig.11. Antenna Characteristic at Optimum Optimization

The antenna is then realized with a radius of radiator 23.1623 mm, a ground plane radius 54.4123 mm, length and width of slot 4.1818 mm and 1 mm respectively, Epoxy FR4 substrate with a thickness of 1.6 mm, and a combination of edge shorting pin state : 110000101111110101011010 and shorting pin radius 0,7 mm. the documentation of realized antenna can be seen in **Fig.12**

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Fig.12. Antenna Fabrication

The antenna is then measured using a vector network analyzer to specify the operating frequency and return loss. The measurement result of this parameters shown in **Fig.13**

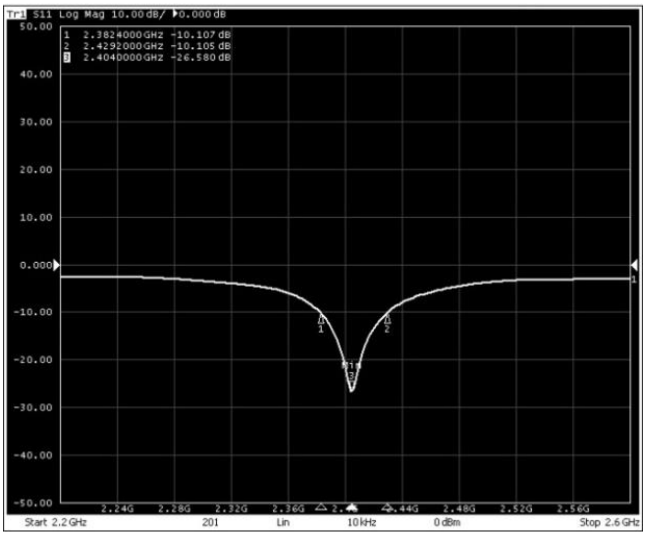

Fig.13. Capture of Return Loss Measurement Result

The figure shows that the lowest return loss value is at the frequency of 2.404 GHz with a value of -26.58 dB. The lower frequency limit and upper frequency limit, at Return Loss -10 dB are 2.3824 GHz and 2.4292 GHz, so the antenna bandwidth impedance is 1.95%

If we compare the results of this measurement with the simulation results as shown in **Fig.14**, we can conclude that the measurement results are slightly shifted from the simulation results. This difference is most likely due to the uncertainty in the fabrication process and the limitations of the measurement instrument and process.

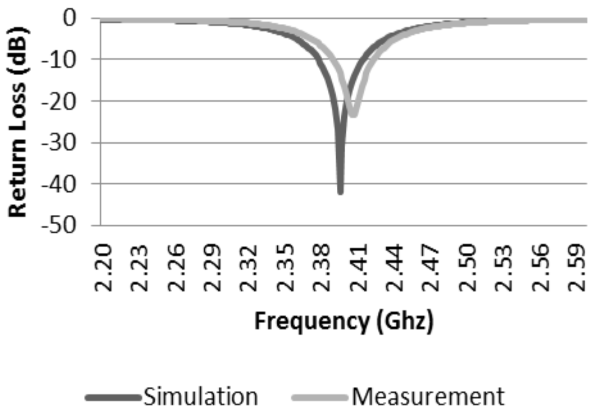

Fig.14. Comparison of Return loss simulations and measurements

Fig.15 shows the comparison of antenna radiation pattern measurements and simulation at phi = 110^o and theta = All. It can be seen that the main beam antenna simulation is around theta = 30^o while the measurements are around theta = 20^o and 60^o. This difference is caused by the limitations of measurement instruments and process and also uncontrolled environmental conditions.

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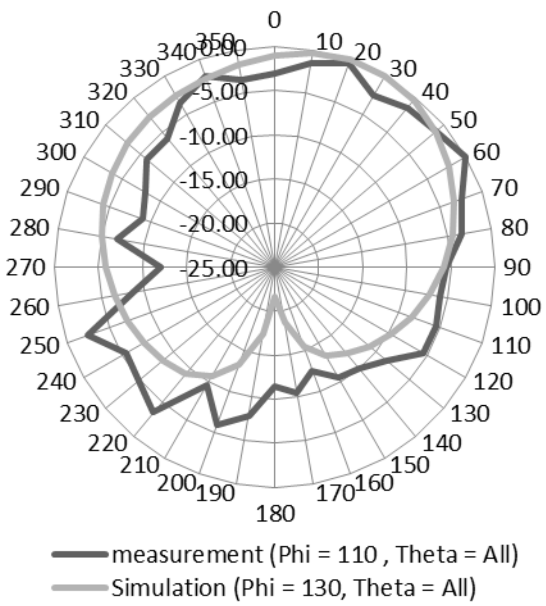
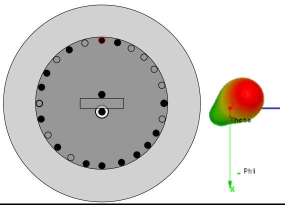
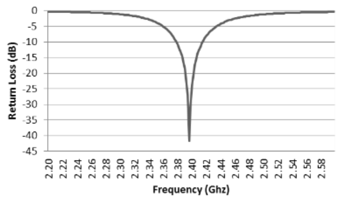


Fig.15. Radiation pattern Comparison

B. Pattern Reconfigurable Mechanism

This antenna design is very potential to be used as a pattern reconfigurable antenna where the change in antenna azimuth radiation pattern is obtained by changing the pin shorting edge state. To do that firstly the reference point (red circle in table) as a reference for the first shorting pin should be shifted. And then the state combination of all pins is maintained according to the results of the optimization, which are 110000101111110101011010. The simulation results of radiation pattern and return loss of 12 odd states can be seen in **Table 4**

Table 4. Radiation pattern and return loss of antenna at 12 state

State 1
 
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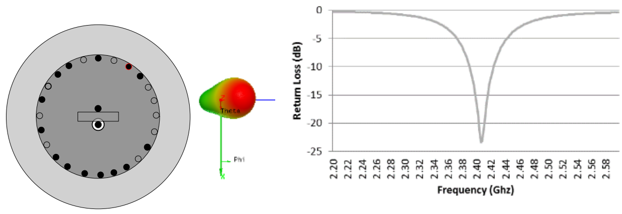
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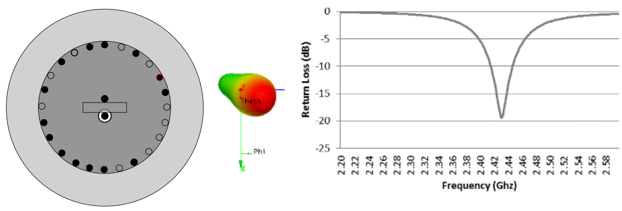
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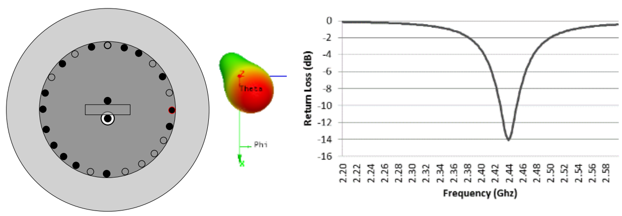
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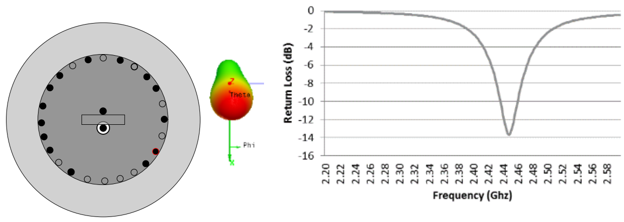
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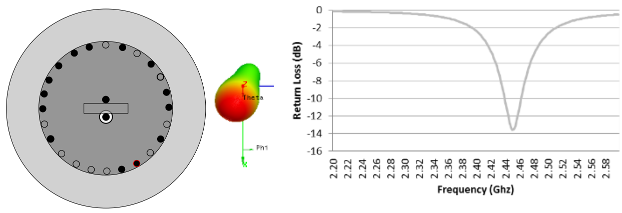
State 13

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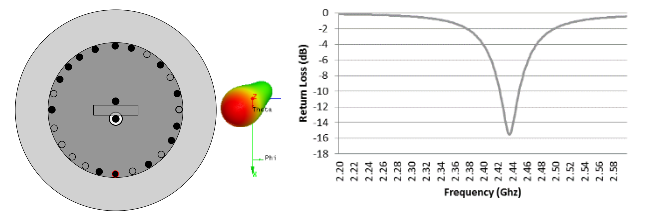
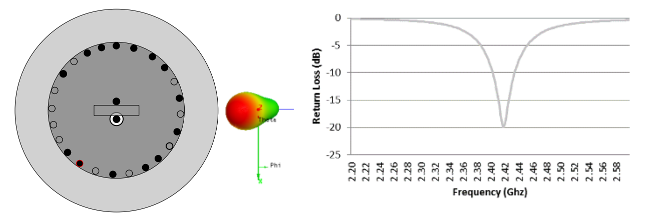


State 15



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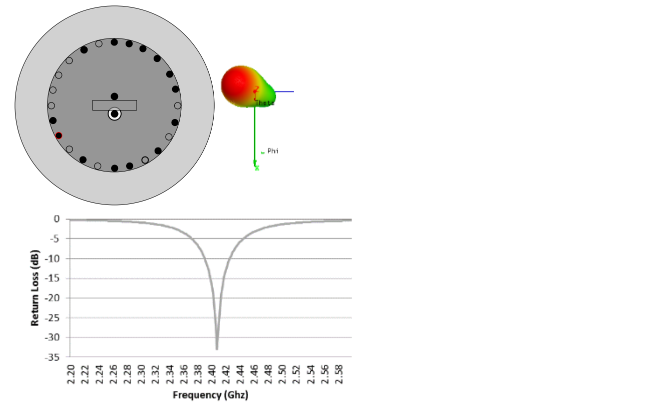

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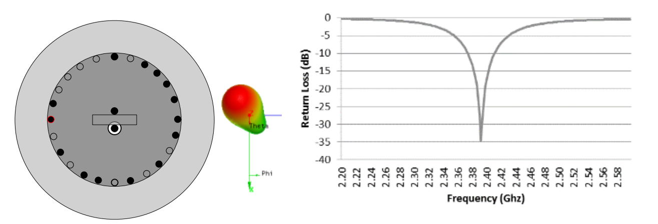

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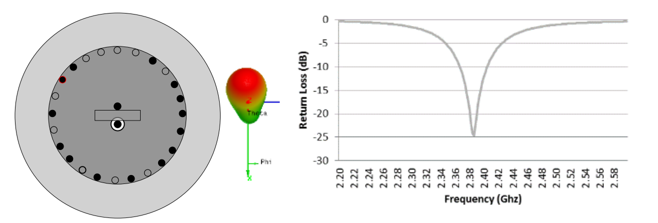

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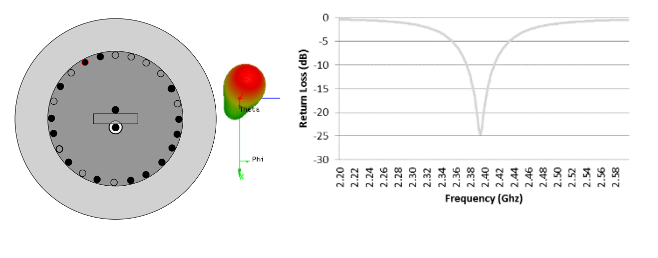

From the **Table 4** it can be seen that radiation pattern changes in the azimuth plane are very potential to be used for pattern reconfigurable purpose. The main beam antenna can be switched and can sweep 360° on azimuth plane. However, because the structure of the antenna is not purely symmetrical, it seems that the operating frequency of antenna shifts slightly, as a result, these potential radiation patterns being more limited in application.

V. CONCLUTIONS

Optimization of a planar radiator structure has been carried out using a feed probe where a shorting pin and slot are attached near the feed point. Both elements are intended to control the matching impedance condition. Then the edge of the radiator is arranged as many as 24 shorting pins called edge shorting pins that is intended to adjust the radiation pattern of the antenna.

Optimization is done using a genetic algorithm in three variables that greatly affect the antenna operating frequency, the matching conditions, and the radiation pattern.

Optimization procedures get an antenna design that is directed towards 45° in the elevation plane. In the azimuth plane, it can be used as a pattern reconfigurable antenna that can be switched and can sweep across all direction. Although theoretically this antenna has a 24-way switch beam capability in the azimuth plane, but due to a slight frequency shift when switched from one state to another due to the asymmetry of the antenna structure, the reconfigurable degree of this antenna is slightly limited.

REFERENCES

[1] Zhang Jiajie, Wang Anguo, and Wang Peng, "A Survey on reconfigurable antennas," , Nanjing, China, 2008.

[2] NaserOjaroudiParchin et al., "Recent Developments of Reconfigurable Antennas for Current and Future Wireless Communication Systems," vol. II, no. 8, 2019.

[3] Jiawei Dong, Yongxiang Li, and Biao Zhang, "A Survey on Radiation Pattern

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Reconfigurable Antennas," in 2011 7th International Conference on Wireless Communications, Networking and Mobile Computing, Wuhan, China , 2011.

[4] Yang Yang and Xi Zhu, "A Wideband Reconfigurable Antenna With 360° Beam Steering for 802.11ac WLAN Applications," IEEE Transactions on Antennas and Propagation (Volume: 66 , Issue: 2 , Feb. 2018), pp. 600-608, 2018.

[5] Sowmyadevi A et al., "2.45 GHz Pattern Reconfigurable Antenna for Wireless Sensor Network applications," in 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC), New Delhi, India, India , 2019.

[6] Pei-Yuan Qin, Shu-Lin Chen, Wei Lin, and Richard W. Ziolkowski Y. Jay Guo, "Advances in Reconfigurable Antenna Systems Facilitated by Innovative Technologies," IEEE Access , 2018.

[7] QingshengZeng, Jinxin Li, and TayebDenidni, "Solution for Overcoming Interference - Radiation Pattern Reconfigurable Antennas," in 2018 International Conference on Electromagnetics in Advanced Applications (ICEAA), Cartagena des Indias, Colombia , 2018.

[8] Guangwei Yang, Jianying Li, Dujuan Wei, Shi-gang Zhou, and RuiXu, "Pattern Reconfigurable Microstrip Antenna With Multidirectional Beam for Wireless Communication," IEEE Transactions on Antennas and Propagation, vol. 67, no. 3, pp. 1910 - 1915, March 2019.

[9] AbdelheqBoukarkar et al., "Compact mechanically frequency and pattern reconfigurable patch antenna," IET Microwaves, Antennas & Propagation, vol. 12, no. 11, pp. 1864 - 1869, Desember 2018.

[10] Wei-Dong MA, Guang-Ming WANG, Ya-Wei WANG, and Bin-Feng ZONG, "Compact Microstrip Antenna with Pattern-Reconfigurable Characteristic," Radioengineering, vol. 26, no. 3, pp. 662-667, September 2017.

[11] Tao Zhang, Su-Ying Yao, and Yong Wang, "Design of Radiation-Pattern-Reconfigurable Antenna With Four Beams," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 183 - 186, 2014.

[12] Mohammed CherifDerbal, AbdelbakiZeghdoud, and MouradNedil, "A Novel Dual Band Antenna Design for WiFi Applications Using Genetic Algorithms," in 2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Boston, MA, USA , 2018.

[13] Francisco das Chagas Barbosa de Sena and José Patrocínio da Silva, "Harmonic suppression using optimised hexagonal defected ground structure by genetic algorithm," IET Microwaves, Antennas & Propagation , vol. 12, no. 10, pp. 1645 - 1648, August 2018.

[14] DwiAndiNurmantris, HeroeWijanto, and BambangSetiaNugroho, "A pattern reconfigurable of circular short-circuited patch antenna based on Genetic Algorithm," 2014 2nd International Conference on Information and Communication Technology (ICoICT), 2014.

[15] DwiAndiNurmantris, HeroeWijanto, and BambangSetiaNugroho, "Pattern Reconfigurable Patch Antenna menggunakan Edge Shorting Pin dan Symmetrical Control Pin," ELKOMIKA: JurnalTeknikEnergiElektrik, Teknik Telekomunikasi, &TeknikElektronika, pp. 177-190, 2015.

[16] ZhiNing Chen and M.Y.W. Chia, "Center-Fed Microstrip Patch Antenna," IEEE Transactions on Antennas and Propagation, vol. 51, no. 3, pp. 483 - 487, March 2003.

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