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Development of Square Patch Microstrip Antenna Design by Using Three Dimension Finite Difference Time Domain Methods

Hla Myo Tun, Devasis Pradhan, Manjusha Behera, Myat Su Nwe, Su Mon Aye, Aye Than Mon, Zaw Min Niang

***Abstract*—The paper mainly focuses on developing a Square-shaped Microstrip Patch Antenna Design using Three Dimension Finite Difference Time Domain Methods. There have been many time steps for analyzing the electric field in the antenna design. The time step has been started from 0 ps to 1991 ps. The electric field changes from the starting point to the end of the time step prove the analysis of the developed antenna system's input signal and return loss, especially the square-shaped microstrip patch antenna based on the FDTD technique. The simulation results confirm that the fabricated antenna system is a perfect candidate for high-frequency purposes. The analysis has been developed by using MATLAB language.**

Keywords—Antenna Engineering, Finite Difference, Mathematical Modeling, Numerical Analysis, Square Patch Microstrip Antenna, Time Domain

I. INTRODUCTION

In contemporary wireless sensor and wireless communication systems, there is a high request for the incorporation of antennas not only with radio frequency (RF) front-end circuits but also with intermediate frequency (IF) or baseband constituents. Moreover, with technological advancement, there is a way of miniaturizing components in various fields. Particularly for high-frequency (such as millimetre-wave) solicitations, the patch antenna size might be considerably smaller associated with the printed circuit board substrate, where the analogue and digital devices are assimilated. Moreover, a microstrip patch antenna probably may be an essential key for the integration of equipment in microwave integrated circuit technology according to its abilities such as lightweight, small volume, low-profile planar conformation and ease of mass fabrication using printed-circuit knowhow leading to a low production cost of microstrip antennas. Consequently, it can be widely used in many applications such as aircraft, missiles, satellites, handheld mobile telephones, and many others [1].

In early 1953, Deschamps originally proposed the concept of a printed microstrip radiator directly to the first microstrip patch antenna later in 1974. The typical structure of a microstrip resonator consists of an upper conductor which can take different shapes and sizes, as demonstrated in Fig. 1. The metallic radiating patch is fabricated on top of a thin dielectric substrate, and a ground surface at the bottom of the antenna substrate as can be realized in Fig. 2. Rectangular, square and circular are the most popular shapes because they are tranquil to fabricate and analyze [4-5].

The dimensions of the patch are unswervingly proportional to the resonant frequency. Microstrip patch antennas can operate in dual and triple frequency operations. The microstrip patch antenna has the springiness of assigning the feeding portion in the microstrip patch antenna wherever inside the patch to match the input impedance. The critical drawback of the microstrip patch antenna is its constricted bandwidth, a small value in gain and low power handling capability [6-7]. The benefit essential in a patch antenna is the capacity to have diversity of polarization. It means microstrip patch antennas can undoubtedly be created to partake in Vertical Polarizations, Horizontal Polarizations, Right Hand Circular Polarizations (RHCP) or Left Hand Circular Polarizations (LHCP) , using various feeding points or a single feeding point with a disproportionate patch structure. There are several ways to acquire circular polarization for the patch antennas. The single-feed patch antennas use the truncated corner, truncated circle, corner feed or slots in the patch [8-9].

II. MICROSTRIP PATCH ANTENNA

A. Proposed Model

The initial design of a microstrip patch antenna was done by mathematical calculation to create a rough model to begin simulations. The design equations are listed below [10].
The width of the resonant patch is

$$W = \frac{\lambda}{2}\left[\frac{\varepsilon_r + 1}{2}\right]^{-\frac{1}{2}} \tag{1}$$

where W =the width of the patch
ε_r =the dielectric constant of the antenna substrate
λ =the wavelength of resonant frequency

The length of the resonant patch is

$$L = 0.5 \times \frac{\lambda}{\sqrt{\varepsilon_r}} - 2\Delta L \tag{2}$$

where L = the length of the patch
ΔL = the fringing length

The extended length of the microstrip patch attributable to the fringing field is given by

$$\Delta L = 0.412 \times \frac{\left(\varepsilon_r + 0.3\right)\left(\frac{W}{t} + 0.264\right)}{\left(\varepsilon_r - 0.258\right)\left(\frac{W}{t} + 0.8\right)} \times t \tag{3}$$

where t = the thickness of copper
Effective dielectric constant:

$$\varepsilon_{re} = \frac{\left(\varepsilon_r + 1\right)}{2} + \frac{\left(\varepsilon_r - 1\right)}{2} \times \left[L + 12 \times \frac{h}{W}\right]^{-\frac{1}{2}} \tag{4}$$

where h = the height of the substrate
The ground plane has a comparable dimension to the substrate but is superior to the dimensions of the patch

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antenna by six epochs of the thickness of the substrate. The measurements for the substrate and ground surface will be specified in Equations (5) and (6) [7].

$$L_g = 6h + L \quad (5)$$

$$W_g = 6h + W \quad (6)$$

where L and W are the length and width of the microstrip patch antenna, individually, while L_g and W_g are the length and width of the ground surface, correspondingly. Fig.1 shows the structure of the proposed antenna design. The fabricated antenna also matches the given parameters in Table I.

TABLE I. DIMENSIONS OF PROPOSED ANTENNA

Parameter	Description	Dimensions
W_s	Length of the Substrate	47.63mm
L_s	Width of Substrate	47.63mm
W_p	Width of the Microstrip Patch	27mm
L_p	Length of the Microstrip Patch	27mm
h	Thickness of the Substrate	1.6mm
sL	Truncate Corner Length	7.07mm
a	Slot Width	1.41mm
b	Slot Length	15.56mm
W_f	Feed Width	2.88mm
L_f	Feed Length	10.32mm
W_s	Length of the Substrate	47.63mm
L_s	Width of Substrate	47.63mm

The designed antenna has been intended to be an FR4 substrate with a 1.6 mm thick-singled layer consuming a ε_r of 4.4. The total dimensions of the antenna are 47.63 mm × 47.63 mm × 1.6 mm. We have utilized an amalgamation of double truncated bends and symmetric Vee-shaped gashes on a radiating patch to enhance the axial ratio result and frequency response. The measurements of the terrazzos and the bend of the V-shaped symmetric slits are accustomed to creating resonance polarization and circular polarization at 2.45 GHz. We have also introduced a diagonal slot on an upper patch to afford circular polarization. In this design, we have utilized a microstrip line feeding technique to arrange for impedance matching of the patch antenna. This feeding technique is precise and extensively used because it is straightforward to scheme, examine, and fabricate. To achieve suitable impedance matching, an inset cut can also be completed. The length of the inserted slot could be organized by the impedance matching [12-15].

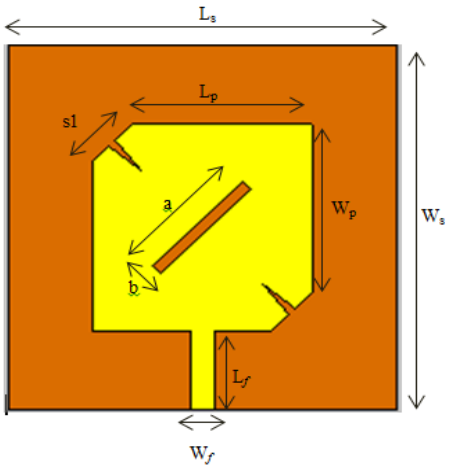


Fig. 1. Proposed Antenna Geometry

B. Antenna Configuration

Polarization with a circular pattern is hypothetically conceivable from a microstrip patch antenna motivated by a single feeding if two spatially orthogonal approaches are encouraged in phase quadrature [5]. The leading concern of this study is to investigate the polarization of the microstrip patch antenna to give a better solution to get the high performance of the patch antenna. Therefore, we use techniques for receiving a polarized with circularly patterned square-shaped microstrip patch antenna with a high gain and impedance matching in the present study.

III. FINITE DIFFERENCE TIME DOMAIN

The finite Difference Time Domain (FDTD) technique is an accepted exercise for investigating quantum materials and devices in semiconductor electronics technology for research commitments [11]. That exercise can elucidate a discretized Schrödinger model in an iterative advancement. On the other hand, the model offers only second-order scrupulous numerical categorizations and essentials that the spatial grating size and time step should ensure minimal circumstances to prevent the numerical categorizations from swerving. A minutiae depiction of the FDTD scheme is deliberated in the succeeding subdivisions.

A. Mathematical Equations of FDTD for Magnetic Fields

The prevailing equalities for defining the finite difference condition are revealed in the succeeding subdivision. Initially, the finite difference equations for H_x, H_y, and H_z for magnetic field terms.

$$\frac{E_z^{i,j+1,k}\Big|_t - E_z^{i,j,k}\Big|_t}{\Delta y} - \frac{E_y^{i,j,k+1}\Big|_t - E_y^{i,j,k}\Big|_t}{\Delta z} = -\frac{\mu_{xx}^{i,j,k}}{C_0} \times \frac{\tilde{H}_x^{i,j,k}\Big|_{t+\frac{\Delta t}{2}} - \tilde{H}_x^{i,j,k}\Big|_{t-\frac{\Delta t}{2}}}{\Delta t} \quad (7)$$

$$\frac{E_x^{i,j,k+1}\Big|_t - E_x^{i,j,k}\Big|_t}{\Delta z} - \frac{E_z^{i+1,j,k}\Big|_t - E_z^{i,j,k}\Big|_t}{\Delta x} = -\frac{\mu_{yy}^{i,j,k}}{C_0} \times \frac{\tilde{H}_y^{i,j,k}\Big|_{t+\frac{\Delta t}{2}} - \tilde{H}_y^{i,j,k}\Big|_{t-\frac{\Delta t}{2}}}{\Delta t} \quad (8)$$

$$\frac{E_y^{i+1,j,k}\Big|_t - E_y^{i,j,k}\Big|_t}{\Delta x} - \frac{E_x^{i,j+1,k}\Big|_t - E_x^{i,j,k}\Big|_t}{\Delta y} = -\frac{\mu_{zz}^{i,j,k}}{C_0} \times \frac{\tilde{H}_z^{i,j,k}\Big|_{t+\frac{\Delta t}{2}} - \tilde{H}_z^{i,j,k}\Big|_{t-\frac{\Delta t}{2}}}{\Delta t} \quad (9)$$

B. Mathematical Equations of FDTD for Electric Fields

The second expression is discovering the electric field terms based on E_x, E_y, and E_z from Maxwell's Equations.

$$\frac{\tilde{H}_z^{i,j,k}\Big|_t - \tilde{H}_z^{i,j-1,k}\Big|_t}{\Delta y} - \frac{\tilde{H}_y^{i,j,k}\Big|_t - \tilde{H}_y^{i,j,k-1}\Big|_t}{\Delta z} = -\frac{\varepsilon_{xx}^{i,j,k}}{C_0} \times \frac{E_x^{i,j,k}\Big|_{t+\Delta t} - E_x^{i,j,k}\Big|_t}{\Delta t} \quad (10)$$

$$\frac{\tilde{H}_x^{i,j,k}\Big|_t - \tilde{H}_x^{i,j,k-1}\Big|_t}{\Delta z} - \frac{\tilde{H}_z^{i,j,k}\Big|_t - \tilde{H}_z^{i-1,j,k}\Big|_t}{\Delta x} = -\frac{\varepsilon_{yy}^{i,j,k}}{C_0} \times \frac{E_y^{i,j,k}\Big|_{t+\Delta t} - E_y^{i,j,k}\Big|_t}{\Delta t} \quad (11)$$

$$\frac{\tilde{H}_y^{i,j,k}\Big|_t - \tilde{H}_y^{i-1,j,k}\Big|_t}{\Delta x} - \frac{\tilde{H}_x^{i,j,k}\Big|_t - \tilde{H}_x^{i,j-1,k}\Big|_t}{\Delta y} = -\frac{\varepsilon_{yy}^{i,j,k}}{C_0} \times \frac{E_z^{i,j,k}\Big|_{t+\Delta t} - E_z^{i,j,k}\Big|_t}{\Delta t} \quad (12)$$

IV. Results and Discussions

The calculated consequence of return loss value, VSWR value, axial ratio value, and radiation pattern of designed circularly polarized symmetric V slits microstrip patch antenna operating frequency at 35 GHz for the dimension expressed earlier. Fig.2 shows the Electric Field Element at t=0 ps.

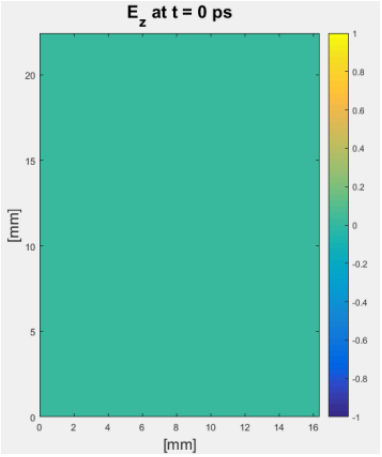


Fig. 2. Electric Field Element at t=0 ps

Fig. 3 demonstrates the Electric Field Component at t=40 ps. We can catch the electric field's starting point at 8mm for the feed line of the square patch microstrip antenna.

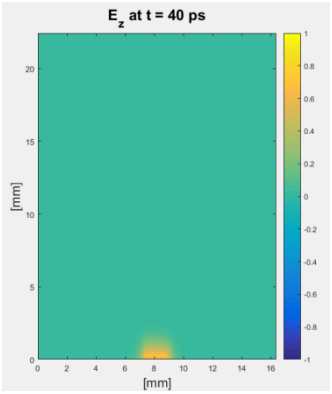


Fig. 3. Electric Field Component at t=40 ps

Based on the following figures of the simulation results from Fig. 3 to 8, the electric field distribution could be quickly recorded using the various time steps of the simulation process. Fig.4 demonstrates the Electric Field Component at t=80 ps.

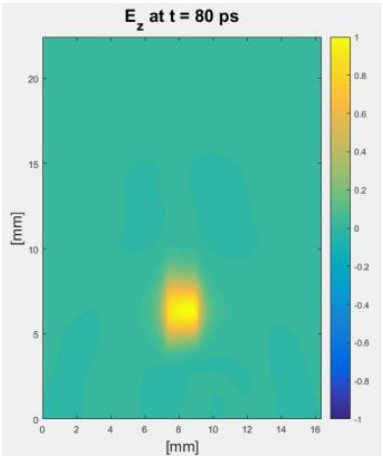


Fig. 4. Electric Field Component at t=80 ps

Fig.5 mentions the Electric Field Component at t=120 ps.

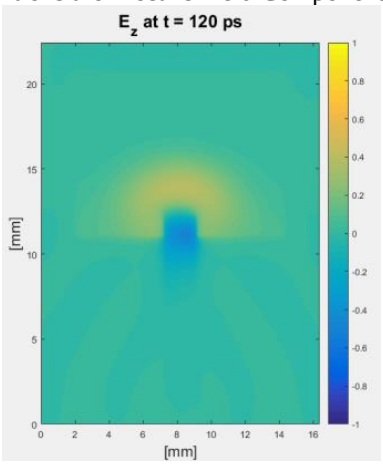


Fig. 5. Electric Field Component at t=120 ps

Fig. 6 points out the Electric Field Component at t=160 ps.

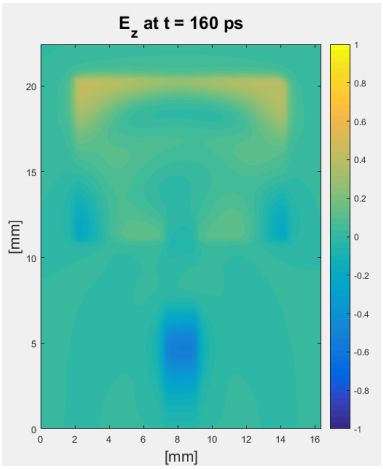


Fig. 6. Electric Field Component at t=160 ps

Fig. 7 offers the Electric Field Component at t=200 ps.

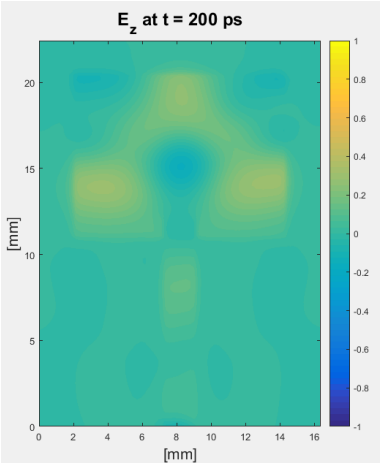


Fig. 7. Electric Field Component at t=200 ps

Fig.8 expresses the Electric Field Component at t=1991 ps.

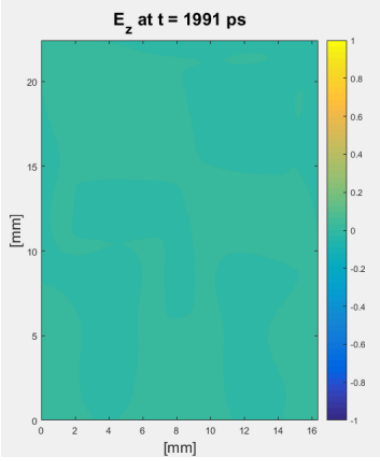


Fig. 8. Electric Field Component at t=1991 ps

Fig. 9 proves the Input and Port 1 Signals concerning Time. The S11 parameter (return loss) designates the association between the input power value and reflected power value to the measurement for a network with two ports.

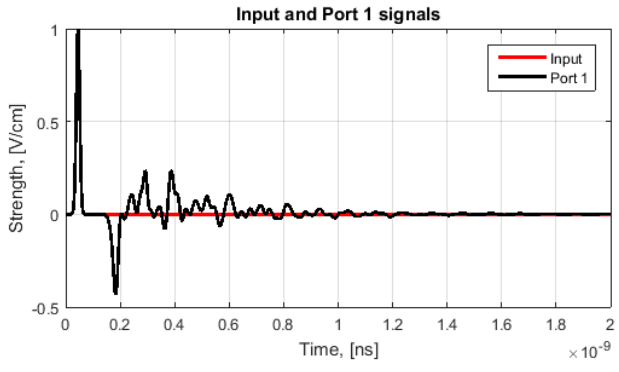


Fig. 9. Input and Port 1 Signals concerning Time

The transmission line and load (antenna) are improved and complemented if the S11 is lower. A lower S11 also means that less power is imitated. Also, the return loss value is the quantity of efficient power conveyed between the feeding lines and microstrip patch antenna.

Fig.10 confirms the return loss (RL) value from Antenna. At the resonant frequency 35GHz, the return loss is -15.669dB. The proposed antenna's resonant is nearly centred at 36 GHz with a return loss of -16 dB as this antenna is resonating at 36GHz, so; it is helpful for S-band applications. This antenna has a bandwidth of 35MHz.

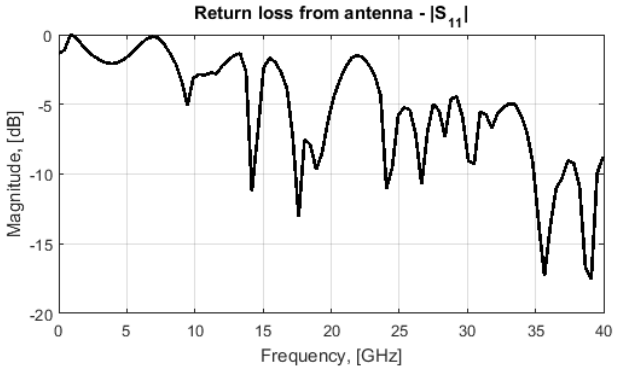


Fig. 10. Return Loss from Antenna

V. Statistic Table for Performance Comparison

The statistic table for the performance comparison of recent works of intelligent antenna design. The statistic table gives valuable information for fabricating the innovative antenna model for high-performance applications.

TABLE II. Statistic Table

Work	*Applications*	*Value*
[13]	GPS Applications	1227.6 MHz
[16]	ISM Frequency Band Applications	2.45 GHz
This Work	5G Applications	35 GHz

VI. Conclusion

This work emphasized fabricating a square microstrip patch antenna for polarization with a circular pattern operating at 35GHz. The dielectric constant value and the thickness value of the substrate material, the profile and magnitude of the top patch and the feeding technique are considered the high-performance condition of the microstrip antenna. For example, by placing a diagonal slot on the microstrip patch, the dimensions of the microstrip antenna might be concentrated. We could see an acceptable axial ratio result from this proposed antenna design to achieve circular polarization. This operates at the frequency of 35 GHz, and this antenna is very suitable for high-frequency communication in the IEEE 802.11 standard, small satellite applications, and S-band. In future, the antenna's performance will be studied by modifying the geometry of the antenna design to achieve a better result with axial ratio and by using the feeding method like a quarter-wave transformer for better results with impedance matching at the resonant frequency of 35GHz.

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Dr. Hla Myo Tun is a Leading Pro-Rector for Research and Engineering Higher Education of Yangon Technological University (YTU). He specializes in professional training for Engineering Higher Education leaders, heads of departments and faculty members. He also directs Research and Development programmes and workshops and works as a certified Quality Assurance Evaluator of the Myanmar Engineering Council (MEngC) since 2019. (email: hlamyotun@ytu.edu.mm).



Devasis Pradhan has worked as an Assistant Professor in Grade 1 and Associate Dean of Research and Development at Acharya Institute of Technology, Bengaluru, Karnataka, from 2017 onwards. His current research includes the effectiveness of 5G Green Communications, mmWave antenna design, UWB antennas, and its implementation. With 16+ years of experience in the Academic and Research field, he has published 76 research papers and eight papers submitted to IEEE Access and Reputed Book and 4 Authored Books and 3 Edited Books (CRC, ISTE, Bentham Science) with a reputed publishing house. (email: devasispradhan@acharya.ac.in).



Manjusha Behera has 17 Years of Teaching experience. She is currently doing research in the domain of digital image processing. Subjects Taught: Analog Electronics Circuits, Information Theory and coding, Electronics Measurement and Instrumentation, Control System, Digital Electronics Laboratory handled: ECN Lab, AIC lab. (email: mbeherafet@kiit.ac.in).



Myat Su Nwe is a Professor of the Department of Mechanical Engineering of King Lauk Phya Institute of Technology Myaungmya. She received her B.Eng. Degree in Mechanical from Technological University (Toungoo) in 2004, her M.Eng. Mechanical in King Lauk Phya Institute of Technology Myaungmya in 2006, and her Ph.D. Degree in Mechanical Engineering at King Lauk Phya Institute of Technology Myaungmya in 2008, respectively. She has published in more than 50 peer-reviewed journals around the world. (email: myatsunwe@gmail.com).



Su Mon Aye is the Associate Professor of the Department of Electronic Engineering of Technological University (Pathein). She received her B.Eng. Degree in Electronics from Technological University (Pathein) in 2005, her M.Eng. Degree in Electronics from West Yangon Technological University in 2011, and her Ph.D. Degree in Electronic Engineering from Mandalay Technological University in 2014, respectively. She published 14 peer-reviewed journals in the world. (email: ecdepartment.ytu@gmail.com).



Aye Than Mon is the Professor and Head of the Department of Electronic Engineering of Technological University (Pathein). She received her B.Eng. Degree in Electronics from Technological University (Pathein) in 2005, her M.Eng. Degree in Electronics from West Yangon Technological University in 2011, and her Ph.D. Degree in Electronic Engineering from Mandalay Technological University in 2014, respectively. She published 14 peer-reviewed journals in the world. (email: ecdepartment.mtu@gmail.com).



Zaw Min Niang is a Deputy Director General of Renewable Energy & Electronic Technology Research Centre under the Department of Research and Innovation (DRI), Ministry of Education (MOE), Myanmar. He received his B.Eng. degree from Yangon Institute of Technology (YIT) in 1992, M.Eng. degree from YTU in 1999, and Ph.D. from the School of Electrical and Electronics Engineering (EEE), Nanyang Technological University (NTU), Singapore in 2005 all in electronics and communication engineering. He has worked as a supervisor and external examiner for Ph.D. electrical and electronics candidates from Technological Universities under the Ministry of Education. He has supervised about 70 PhD candidates. (email: drzaw290615@gmail.com).