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DESIGNANDSIMULATIONOFRECTANGULARMICROSTRIPPATCHANTENNAFORXBANDAPPLICATION

Strictly as per the compliance and regulations of:

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N. C. Okoro [α] & L. I. Oborkhale [σ]

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I. Introduction

Wireless communication services have been growing at a very rapid rate in recent years (Parchin et al., 2019), and the need for compact and multifunctional wireless communication systems has spurred the development of antennas with small size (Ullah, et al, 2018). With the increasing number of wireless users and limited available bandwidth, wireless service providers are always trying hard to optimize their network for larger capacity and improved quality coverage, as to satisfy the mobility need of users (Yildiran, 2017). This surge has led the field of antenna engineering to constantly evolve, and accommodate the users need for wideband, low-cost, miniaturized and easily integrated antennas (Ab Wahab et al, 2019). Amongst the various types of antennas that include wire antennas and reflector antennas, microstrip patch antennas are the most popular, versatile, and easy to fabricate antennas (Hala, 2010).

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Microstrip antenna is very popular due to its distinguishing characteristics such as low profile, low cost, light weight, ease of fabrication, and conformity to planar and non-planar surfaces (Tarparaet al., 2018). These advantages have made microstrip patch antennas to be widely employed for various civilian and military applications in television, broadcast radio, mobile systems, global positioning system (GPS), radio-frequency identification (RFID), multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, biological imaging, missile guidance, etc (Garg et al, 2001; Liuet al, 2012; Obotet al, 2019).

Nevertheless, despite the advantages offered bymicrostrip antennas, they are associated with some disadvantages, such as low gain, narrow bandwidth, and low power handling capacity (Tarpara et. al., 2018; Ullah et al, 2018). Over the years, a lot of researches have been undertaken to overcome these disadvantages associated with microstrip antennas. Some of the popular techniques proposed by researchers to improve the bandwidth and gain of conventional patch antennas is by using different antenna feeding techniques and dimensions, thick substrate, resonant slots called defected ground structures (DGSs), multi-resonator stacked patch structure (metamaterials), and through the use of array antenna configuration (Islam et al, 2009; Kim, 2010; Liu et al, 2012; Kaur and Rajni, 2013; Khraisat, 2018; Obot et.al., 2019).

The aim of this research work, is to design and simulate an insetfed Rectangular Microstrip PatchAntenna (RMPA) for X-band application. The research pursued a lightweight antenna that operates with an operating frequency of 10GHz in the X-band range of 8-12GHz, and with a high gain, wider beamwidth, and a high radiation efficiency. This research work is most significant in meeting the demand for long distance wireless communication, and for various X-band applications in Synthetic Aperture radar (SAR) onboard aerial platforms. The significant of microstrip antenna design application, as a panacea for achieving effective signal reception in wireless communication system, will avail the communication industry with a market full of lightweight antenna system and devices that offers high gain, improved efficiency, wider bandwidth, agile beam steering, decreased signal interference and increase Signal-to-Noise Ratio (SNR) for various applications in wireless communication systems.

II. Literature Review

Several research papers have reported on design and simulation of microstrip patch antenna. These research works used different design techniques, topologies and electromagnetic simulators to achieve better antenna performance.

Huque, et al., (2011) in their work, designed and analysed a microstrip antenna for X-band applications using SONET simulator. They observed that radiation efficiency declines rapidly with dielectric constant for 10GHz frequency. The designed antennas yielded return losses of -4.21dB to -25.456dB at frequencies around 10GHz for a dielectric substrate with permittivity (εr) of 2.2 and height, h of 1.588 mm. Othman et al., (2014) designed a novalspanar printed antenna for X-band frequency spectrum for 10GHz radar system application using CST microwave Simulation software. The spanar antenna was designed with a small patch size of 24.8 mm x 8.0 mm on a FR4 substrate of 31.7 mm by 18.5 mm, having a thickness (h) of 1.6 mm and a dielectric constant (Ɛr) of 4.7. The designed antenna achieved a gain of 4.123 dBi with a directivity of 5.587 dB and proved to be suitable for wireless system operating at X-band.

In Midasala and Siddaiah (2016), the authors designed and simulated a Rectangular Microstrip Patch Antenna (RMPA) for X-band application using HFSS software. The simulation of designed antenna showed good performance in terms of return loss, VSWR and Gain. In Vijaykumar (2017), a steerable Microstrip patch antenna for UAV applications at 5.6GHz was proposed using HFSS software. To increase the proposed antenna design gain, the author used an inset fed microstrip line. The gain of a single element in set fed patch antenna was found to be 7.2d Biresonating at5.6GHzwith10dBbandwidthrangeof190MHz.In Datto et al. (2017), an optimized Microstrip Patch Antenna was designed and simulated to enhance gain for S-Band application. In this work, the single element MPA is firstly designed on Rogers RT/duroid 5880 substrate using HFSS software quarter wavelength transformer. In Obot et al. (2019), the work addresses the problem of low gain of single microstrip antenna element by designing an inset fed rectangular microstrip antennas using HFSS software. The simulation of the designed antenna achieved a gain of 5.26 dBi at the resonating frequency of 2.4 GHz. In the work of Ab Wahab, et al. (2019), the author designed and simulated an inset-fed rectangular microstrip patch antenna for WLAN application using CST software and a RO4350 dialectic substrate,

The combined work of Nataraj and Prabha. (2019) proposed a design for a Wideband Rectangular Patch Antenna for X- Band Applications. The antenna was printed on an FR4-epoxy substrate with 1.58mm thickness and patch dimensions of 9.13 mm by 6.27 mm. The design was simulated using Advanced Design System (ADS) software and achieved a return loss of -33.53 dB at 10.58 GHz operating resonant frequency, with an overall efficiency of 60-70% in the frequency range of 8-12 GHz.

It can be seen that there has been numerous literature contribution and techniques to designing a microstrip antenna for wireless communication system. Majority of the existing research work in microstrip antenna design has addressed the problems that are closely related with low gain, narrow bandwidth and low power handling capacity. Hence, the significant contribution of microstrip antenna design in reviewed literatures is to enhance the performance of a microstrip antenna to achieve higher gain, wider bandwidth as well as to improve the power handling capacity of microstrip antenna in wireless communication devices.

III. Design Methodology

The present aim of the research work is to design and simulate a rectangular microstrip patch antenna for X-band application. To achieve this, the choice of simulating software, design specifications and parameter (dimension) calculations to achieve a light-weighted microstrip patch antenna should be considered.

a) Choice of Simulation Software

To design a microstrip patch antenna, several software can be employed such as: COMSOL, MATLAB, IE3D, MWO, SONNET, FEKO, ADS, HP MDS, CST MS and HFSS etc (Odeyemi et al, 2011; Patir, 2015). However, for this research work, the ANSYS HFSS (v.15) software is chosen for design and simulation, as it is based on the Finite Element Method (FEM) techniques (Felippa, 2004). The HFSS software is the most accurate, versatile and appropriate for modelling volumetric structures like the Microstrip patch antenna.

b) Design Procedure

The procedure to achieve the design and simulation of an inset-fed rectangular microstrip patch antenna involves the following steps:

1. Specifying the frequency of operation called resonant frequency (f_o)
2. Choose a suitable dielectric substrate material
3. Decide on the substrate height (h)
4. Calculate the appropriate patch dimensions (width and length)
5. Select a feeding method
6. Find the feed location.

c) Design Specification

Before designing a microstrip patch antenna, the first step is to consider the design specification of the antenna based on its intended application. There are three essential design specifications that must be considered when designing a Rectangular Microstrip Patch Antenna for various wireless application. These are:

1. Frequency of Operation (f_o): The proposed antenna is intended for X-band application range of 8 – 12 GHz, for UAV and radar wireless communication system. Thus, an operating frequency (f_o) of 10 GHz in the X-band range of 8 – 12 GHz is selected for the antenna design.
2. Dielectric Substrate Material (ε_r: While designing MPA, substrate selection is as decisive as the design itself. Radiating properties of MPAs depend on the substrate used for the antenna design (Hanumante and Roy, 2012). The substrate material chosen for the design of the RMPA is Rogers RO4350 with a dielectric constant (ε_r) of 3.66 and aloss tangent (δ) of 0.0032. A substrate with a relatively low dielectric constant is selected since it will reduce the patch size of the antenna, desirable for radar application of the proposed X-band antenna. The reason for choosing a ROGERS substrate is however, due to its consider able properties, such as, low surface wave excitation, low moisture absorption, lowest electrical loss, uniform electrical properties over frequency, and relatively low cost (Rogers, 2020).
3. Height of dielectric substrate (h): For the microstrip patch antenna to be used for X-band application of 10GHz, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate (thickness) selected is 31 ml (≅ 0.79 mm). This height of the RMPA is chosen based on the equation given by Kumar and Ray, (2003) as:

$$h \leq \frac{0.3c}{2\pi f_o \sqrt{\varepsilon_r}}$$

where, c is velocity of light in mm and f_o is the operating frequency in GHz.

The other factor considered in the design specification, is the feeding method for the proposed antenna. For this research work, the inset feed microstrip line feed technique is to be employed. Table 1 shows the design specifications, which is used for the design of proposed antennas.

Table 1: Microstrip Antenna Design Specifications

Parameters	Operating Freq (f_o)	Substrate	Dielectricconstant (ε_r)	Substrate Height (h)	Feeding Method
Specification	10 GHz	Roger RO 4350	3.66	31 ml	Inset-fed

d) Design of Rectangular Microstrip Patch Antenna

To design the proposed inset-fed RMPA, design parameter dimensions of the antenna need to be developed, using essential equations required to perform this process. The transmission line model is used to calculate the design parameters of the antenna, because it gives a good practical and easy insight into the design of the RMPA.

i. *Calculations of Design Parameters*

The detailed procedure and parameter equations for designing the single element, single band rectangular microstrip patch antenna are as follows:

Step 1: Calculation of the patch width (W):

For an efficient radiator, the width (W) of the microstrip patch is calculated based on the transmission line model equation given by (Balanis, 2016) as:

$$W = \frac{c}{2f_o}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Substituting $c = 3 \times 10^{11}\ mm/s$, $\varepsilon_r = 3.66$ and $f_o = 10\ GHz$, $W = 10\ mm$

Step 2: Calculation of effective dielectric cconstant (ε_{eff}):

The effective dielectric constant is obtained Matin and Sayeed (2010) as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Substituting $\varepsilon_r = 3.66, W = 10\ mm$ and $h = 31ml$ (0.79 mm), $\varepsilon_{eff} = 3.28$

Step 3: Computation of effective length (L_{eff}) of patch:

The effective length of the patch is calculated from Balanis (2016) as:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

Substituting $c = 3 \times 10^{11}\ mm/s, f_r = 10\ GHz$ and $\varepsilon_{reff} = 3.28$, we get: $L_{eff} = 8.28\ mm$

Step 4: Estimating the patch length extension(ΔL):

The patch length extension is obtained from Garg, et al. (2013) as:

$$\Delta L = \frac{0.412h(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)}$$

Substituting $\varepsilon_{eff} = 3.28, W = 10\ mm$ and $h = 31\ ml$ (0.79mm), weget: $\Delta L = 0.37\ mm$

Step 5: Calculation of the actual length of the patch (L):

The actual (physical) length of the patch is calculated from (Kumar et al., 2013) as:

$$L = L_{eff} - 2\Delta L$$

Substituting$L_{eff} = 8.28\ mm$, and$\Delta L = 0.37\ mm$, we get: $L = 7.5\ mm$

Step 6: Determination of the inset feed depth (y_0):

An inset-fed microstrip line feed is to be used in this design. The feed depth is given by y_0. The feed point must be located at that point on the patch, where the input impedance (Z_0) is 50 ohms for the resonant frequency. The resonant input edge resistance (Z_{in}) of the rectangular patch is estimated using an online microstrip patch antenna calculator (em.talk, 2011) as $Z_{in} = 209.7\Omega$. Therefore, the inset feed depth (y_0) is calculated from Matin and Sayeed (2010) as:

$$y_0 = \frac{L}{\pi} cos^{-1} \sqrt{\frac{Z_0}{Z_{in}}}$$

Substituting $Z_0 = 50\Omega$, $Z_{in} = 209.7\Omega$, and $L = 7.5\ mm$, we get: $y_0 \cong 2.6\ mm$

Step 7: Calculation of the width of microstrip line (W_o):

The width of microstrip line (W_o) is determined according to Pozar (2012) as:

$$\frac{W_o}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & for\ \frac{W_o}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] & \frac{W_o}{h} > 2 \end{cases}$$

Using the formula for $\frac{W_o}{h} > 2$, and substituting for $B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$, the above equation becomes:

$$W_o = \frac{2h}{\pi}\left[\frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1 - \ln\left(\frac{120\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1\right) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln\left(\frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} - 1\right) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right]$$

Substituting $Z_0 = 50\Omega$, $h = 31ml$ (0.79mm) and $\varepsilon_r = 3.66, W_o \cong 1.73mm$

Step 8: Calculation of the inset (feed) gap (g):

The feed gap (notch width) in millimeters is computed based on equation given in Matin and Sayeed (2010) as:

$$g = \frac{4.65 \times 10^{-18} c f_o}{\sqrt{2\varepsilon_{eff}}}$$

Substituting $c = 3 \times 10^{11}\ mm/s, f_o = 10\ GHz$ and $\varepsilon_{eff} = 3.28$,$g = 0.55mm$

Step 9: Determination of the feed length (L_f):

The feed length of the microstrip transmission line can be determined using:

$$L_f = 3h$$

Substituting $h = 31ml$ (0.79mm), we get: $L_f = 2.37\ mm$. However, since this is assumed to be 50Ω microstrip transmission feed line, an online microstrip calculator (em.talk, 2011) was used to determine the transmission line as 2 mm and was added to the inset depth (y_0) of 2.6 mm, to get an optimized length $((L_f)$ of $4.6\ mm$ used as the feed length of the proposed RMPA in this research work.

Step 10: Calculation of ground plane dimensions:

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, Balanis, (2016) stated that it is essential to have a finite ground plane, that is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, the length $(\mathrm{L_g})$ and width of ground plane $(\mathrm{W_g})$ were computed using:

$$\mathrm{L_g} = L + 6h$$

$$\mathrm{W_g} = W + 6h$$

Substituting $L = 7.5mm,, W = 10mm$ and $h = 31ml$, we get: $\mathrm{L_g} = 12.24\ mm$ and $\mathrm{W_g}$ =14.74 mm. However, in this work, a square ground plane dimensions of 40mm by 40mm is used for both $\mathrm{L_g}$ and $\mathrm{W_g}$ respectively of the RMPA design.

ii. *Geometry of Proposed inset-fed RMPA Design*

Based on the calculated design parameters, the proposed antenna geometry of the inset fed Rectangular Microstrip Antenna (RMPA) is as shown in Fig.2.

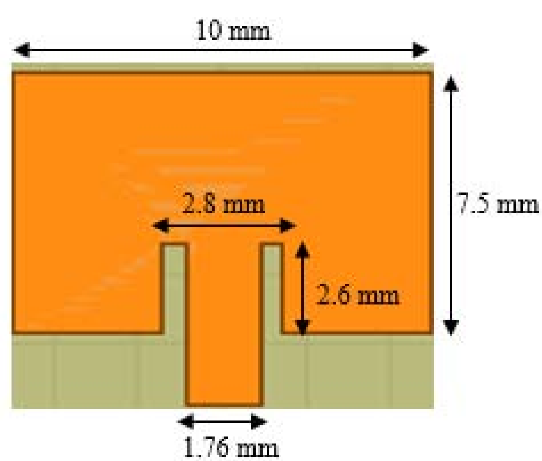


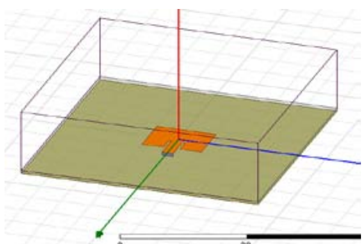
Fig. 2: Top-view dimensions of inset-fed RMPA Design

The summary of the optimized design calculations and specifications for various dimensions of patch, ground plane and matching inset feed line for the proposed inset-fed RMPA is given in Table 2 below.

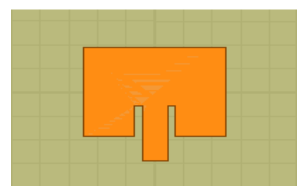
Table 2: Dimensions for the proposed inset fed RMPA

Parameters		Dimensions
(a)	**Patch dimensions**	
	Width of the patch (W)	10 mm
	Length of the patch (L)	7.5 mm
(b)	**Ground plane dimensions**	
	Length of the ground plane (L_g)	40 mm
	Width of the ground plane (W_g)	40 mm
(c)	**Inset feed line dimensions**	
	Inset feed depth (y_0)	2.6 mm
	Inset feed gap (g)	2.8 mm
	Feed length of 50Ω microstrip line (L_f)	4.6 mm
	Width of 50Ω microstrip line (W_0)	1.76 mm
	Characteristic impedance offeedline (Z_0)	50 Ω

The designed inset-fed RMPA in HFSS is shown in Fig. 3 below.



(a): 3D view of RMPA



(b): 2D view of RMPA

Fig. 3: Designed inset-fed RMPA using HFSS software

IV. Results and Discussion

The simulation results of the single element RMPA using HFSS (v.15) software are shown from Fig. 4 to Fig. 9. The HFSS software that has been used to simulate the antenna design has the ability to display several antenna parameters such as return loss (S_{11}), VSWR, gain, directivity, radiation pattern, Half Power Beamwidth (HPBW) and efficiency. To analyze and evaluate the antenna performance of the proposed antenna design using these antenna parameters, the summary of the results of the simulated antenna designs for designed RMPA are presented and discussed below.

a) Return Loss (S_{11})

Return loss is an important parameter that measures the effective power delivery of the designed antenna (Balanis, 2016). Fig. 4 below plots the return loss or reflection response (S_{11}) of the designed RMPA. From Fig. 4, it is evident that the designed RMPA is resonating at the operating frequency of 10 GHz, with a measured return loss of -19.61 dB. This return loss value of -19.61 dB is a good value since it is below (less than) the -9.5 dB minimum specified value for a good practical MPA design, and signifies that minimum power is reflected from the antenna to the source input port.

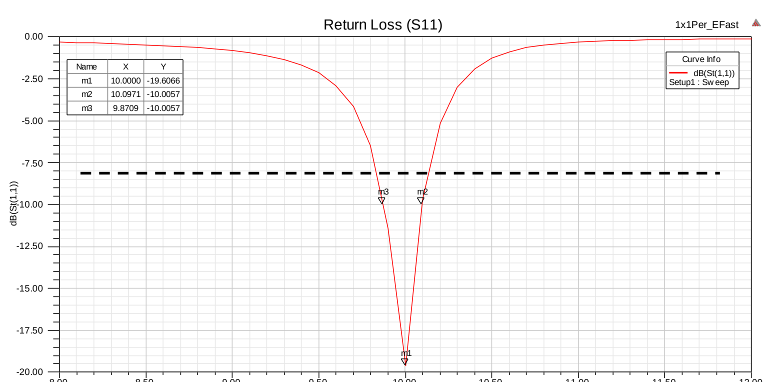


Fig. 4: Return Loss vs frequency plot of designed RMPA

b) Bandwidth

The bandwidth of an antenna is the range of frequencies within which a particular antenna can radiate and receive energy properly (Balanis, 2016). Within this bandwidth limits of the antenna, the characteristics (gain, VSWR, etc) of the designed RMPA provides satisfactory operation (Alsager, 2011). As can be seen from fig. 4, the -10 dB bandwidth of the designed antenna is 226.2MHz, with a resonate frequency of 10GHz.The 226.2MHz impedance bandwidth of the designed antenna is approximately 2.26%, and can further be improved by using antenna array configurations, or by using aperture coupling and several other methods discussed in many literatures.

c) Voltage Standing Wave Ratio (VSWR)

Voltage standing wave ratio (VSWR) is a way to measure transmission line imperfections (Alsager, 2011). The desirable VSWR range of 1<VSWR< 2 is desired for a good antenna operation of any designed antenna (Pozar, 2012). From Fig. 5 below, the designed RMPA, achieved a VSWR of 1.82 at the resonant frequency of 10 GHz. The VSWR value of 1.82 indicates a good impedance matching, as it is slightly below the acceptable maximum value of 2 for a well-matched antenna.

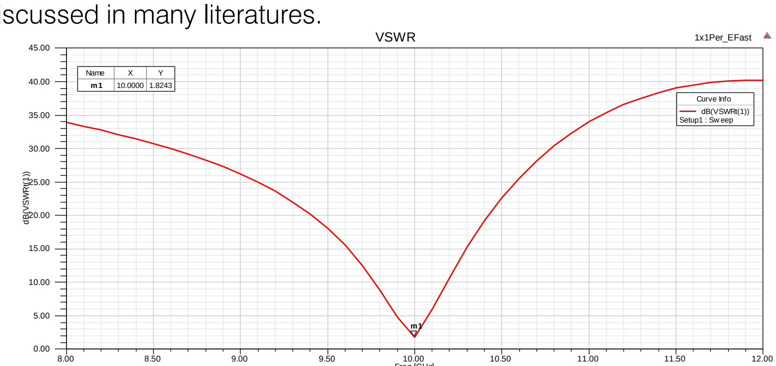


Fig. 5: VSWR versus frequency plot of proposed RMPA

d) Gain and Directivity

The gain of an antenna is the measure of the antenna efficiency, and describes how far signals can travel through space, while the directivity of an antenna measures the ability of the antenna to radiate energy in a particular direction. The higher the gain, the farther signals will travel. The 3D polar plot of the simulated antenna design is shown in fig. 6 and fig. 7 below.

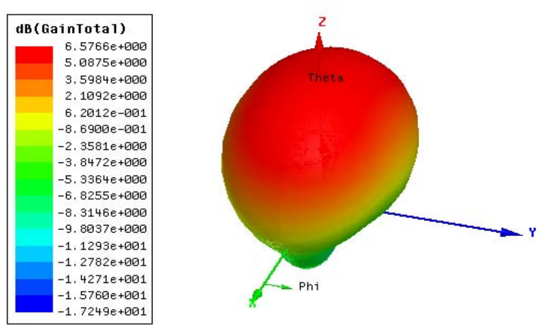


Fig. 6: 3D Gain plot of simulated RMPA

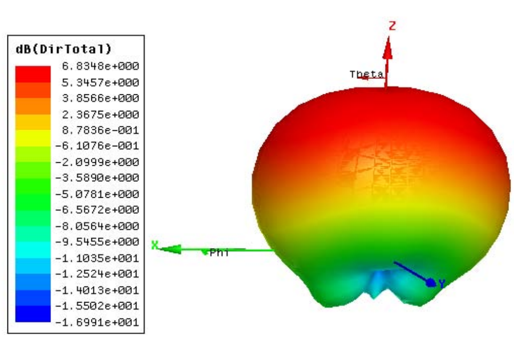


Fig. 7: 3D Directivity plot of simulated RMPA

From the 3D polar plot shown in Fig. 6 and Fig. 7, the gain and directivity of the designed RMPA are 6.58dBi and 6.83 dBi respectively, at the resonant frequency of 10 GHz. Thus, the proposed RMPA is relatively suitable for long communication, as it is less prone to interference and fading, and maybe improved when used in array for improved signal reception in wireless communication system.

e) Radiation Pattern and Beamwidth

Radiation pattern and beamwidth of an antenna describes the shape and direction of the beam of electromagnetic wave from antenna. The measured far-field radiation patterns of designed RMPA antennas are shown in Fig. 8below. The radiation pattern shown in Fig. 8 shows the E-plane (phi=0deg, x-zplane) and H-plane (phi=90deg, y-zplane) radiation pattern of the designed RMPA in polar plot. The radiation pattern of the proposed antenna is omni directional with minimum side lobe.

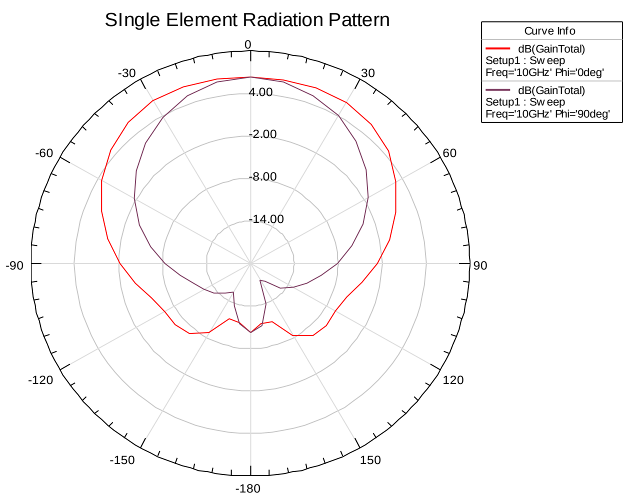


Fig. 8: Radiation pattern of designed RMPA in polar plot

When considering the beamwidth of the designed RMPA, the -3dB Half power Beamwidth (HPBW) of the designed RMPA is 115.2°. The designed RMPA therefore, supports a wider beamwidth, with less directed main-beam and a high chance of receiving interference due to its low gain. Thus, the designed RMPA can be used for WLAN and X-band application.

f) Power Radiated (Tx) and Power Received (Rx)

The power radiated or received by an antenna is an important parameter that characterizes the performance of an antenna, and determines the antenna performance efficiency. The power received by an antenna is expected to be higher than the radiated power by an antenna, as a result of ohmic losses on transmission lines or losses in the dielectric surrounding the patch antenna. In this research work, the power radiated and received by the designed RMPA are tabulated in table 3. As can be seen, the 9.891mW power received by RMPA is higher than the 9.320mW power radiated. This indicates that the proposed RMPA radiates 93.2% of its power received, and absorb less than 6.8% of received power as losses.

Table 3: Comparison of RMPA power radiated & received

Number of Elements	Power Radiated(mW)	Power Received (mW)
Single Element	9.320	9.891

g) Antenna Efficiency

The antenna efficiency of the designed RMPA in this research work, is an important parameter that expresses the ratio of the total power radiated, to the net power received by the antenna. In this research work, the radiation efficiency of the designed RMPA is 94.2%. This high antenna efficiency of 94.2% achieved by the proposed RMPA is therefore good for practical purposes as it is slightly above the 80-90% efficiency noted by Alsager (2011) for most microstrip patch antennas.

V. Summary of Simulation Results and Analysis

The summary of the simulation results of the designed RMPA in this research work is shown in Table 4. This table presents the performance parameters of the designed RMPA in this research work, using the basic antenna parameters characteristics such as resonant frequency, return loss (S_{11}), VSWR, Bandwidth, Gain, Directivity, Half Power Beamwidth (HPBW) and Efficiency.

Table 4: Summary of simulated results of RMPA Design

No. of Elements	Resonant Freq. (GHz)	Return Loss (dB)	VSWR	-10dB Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)	HPBW (Deg)	Efficiency (%)
Single Element	10	-19.61	1.82	226.2	6.58	6.83	115.2	94.2

VI. Conclusion

In this research work, the design and simulation of a microstrip patch antenna for improving signal reception in wireless communication system has been presented. An innovative single element Rectangular Microstrip Patch Antennas (RMPA) resonating at 10 GHz has been successfully designed and simulated using HFSS (v.15) software. The antennas performance characteristics such as return loss, bandwidth, VSWR, gain, directivity, beamwidth and radiation efficiency were obtained in the simulation. The simulation results of the proposed RMPA resonated at 10 GHz, with a return loss of -19.61 dB, bandwidth of 2.26%, VSWR of 1.82, gain of 6.58 dBi, directivity of 6.83 dBi and an antenna efficiency of 94.2%. The novel designed antennas can be used for commercial WLAN, WiMAX, radar and satellite wireless applications in the X-band range of wireless communications.

VII. Future Works and Recommendations

Antenna design is a vast field for researchers and engineers. Future works and recommendations will be to use the single element RMPA to design and simulate a microstrip patch array antenna that improves the antenna performance of the proposed design. As antenna designed in this work is a single band antenna, it would be possible to also extend this work to a multiband design which can operate at multiple frequencies for multiple applications.

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