Design of a Rectangular Microstrip Antenna Resonating at 3.5 GHz for Future Wireless Networks

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***Abstract*—The design and performance analysis of a conventional rectangular microstrip antenna (RMSA) operating at 3.5GHz for future wireless networks and applications is presented. The major components of a microstrip antenna (MSA) are the ground plane, dielectric substrate, patch and feed-line. The dimensions of the components of the RMSA were determined using the transmission line model. The rectangular shaped patch was placed on flame retardant epoxy 4 (FR4) substrate with a dielectric constant (ε_r) of 4.4 and thickness (h) of 1.6 mm. The designed antenna was developed and simulated in Computer Simulation Technology (CST) microwave studio. From the simulation results, the return loss, voltage standing ratio (VSWR), and gain were -31.0 dB, 1.43 and 6.6 dB respectively. Furthermore, the antenna also resonated at the required frequency of 3.5GHZ in the return loss plot. The simulation results antenna performance parameters shows that the antenna can be used for future wireless networks and applications.**

Keywords— Rectangular microstrip antenna, antenna parameters, transmission line model, CST microwave studio.

I. INTRODUCTION

In recent years, the dependency of human activities on network driven applications has increased the need for higher data throughput, lower latency and increase channel capacity for wireless networks leading to the development of new generation networks such as fifth-generation of wireless network also known as 5G [1].

Microstrip antenna (MSA) has been noted as a good alternative to overcome propagation difficulties especially for 5G networks [2]. Reference [3] stated that Deschamps first put forth the MSA idea in 1953 but Munson and Howell created useful antennas in the 1970s with benefits such as small size, light weight and ease of production using printed circuit technology [4], and the ability to build arrays [5]. The shapes of microstrip antennas vary and can be customized to meet specific needs. The popular shapes are the rectangular, circular and square [6]. The desire for compact and minimally framed antennas has increased along with the demands for use in mobile and personal communication, which has elevated MSA to the fore. A microstrip fundamental design comprises a metal strip on a dielectric substrate with a ground plane covering it on the other side.

Several researches have been carried out in the design and performance analysis of MSA leading to many applications according to [7] such as remote sensing and environmental instrumentations, satellite navigation, missiles and telemetry, biomedicine, mobile communication, direct broadcast services, radars and global position system (GPS).

MSA has some attractive features such as light weight, low profile, low cost, simple design, ease in installation, variety of shapes and its compatibility with monolithic microwave integrated circuits (MMICs) that has made it popular in recent times, but also has some significant drawbacks such as narrow bandwidth, low gain, low power handling capabilities and low efficiency [8].

Many authors have designed MSAs for different frequencies in line with their spectral needs and recently in Nigeria the Nigerian Communication Commission (NCC) recently specified the 3.5 GHz to 3.6 GHz band as one of the frequency bands for 5G communication implementation. This paper dwells on the design and performance analysis of a rectangular microstrip antenna (RMSA) resonating at a frequency of 3.5 GHZ for future wireless networks and applications.

II. THEORETICAL FRAMEWORK

Antennas are an integral part of wireless networks. It is the transducer that converts voltage or current signals in a transmission line to electromagnetic waves in space at the transmitter and reversing same at the receiver[6]. It acts as a conducting wire that radiates time varying currents or an acceleration or deceleration of charge. An illustration of the antenna radiation principle is shown in Fig.1.

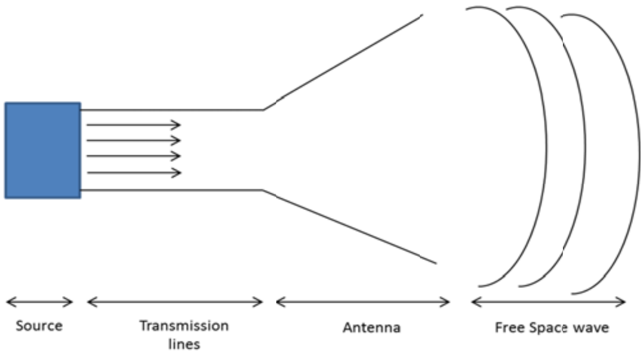

Fig.1. *Illustration of antenna radiation principles [6]*

The four vector-differential equations known as Maxwell's equations control all of electromagnetics, with the exception of quantum mechanics [9]. In the 1800s, James Clerk Maxwell made them available in their entirety for the first time. Although he did not create them entirely on his own, he did complete Ampere's law by adding the displacement current phrase. The following describes Maxwell's differential equations with constitutive relations given by [10]:

$$\nabla \times E = \frac{\partial B}{\partial t} \qquad (1)$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad (2)$$

$$\nabla \times B = 0 \qquad (3)$$

$$\nabla \times D = \rho \qquad (4)$$

Where: E = electric field (V/m); H = magnetic field (A/m); D = electric flux density (C/m^2); B = magnetic flux density (Wb/m^2); J = electric current density (A/m^2) and ρ = electric charge density (C/m^3).

The solution to the fields produced by an impressed current distribution in the antenna problem is J. The easiest way to retrieve the current distribution is to evaluate J in the course of the solution process. However, if, as anticipated, there is a distribution of current and a need to identify the fields E and H, the two curl functions of Maxwell's equations must be obtained [10]. A transmission line's guided waves can transform to free space waves (and conversely in the receiving case) [11].

The basic antenna parameters includes voltage standing wave ratio (VSWR), polarization, efficiency, gain, return loss, directivity, radiation pattern, impedance bandwidth, and half- power beam width (HPBW).The VSWR evaluates the ratio of the amplitude of the minimum and maximum standing wave, and can be evaluated by Equation(5).

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (5)$$

where: V_{min} and V_{max} are the minimum and maximum voltage. Good impedance matching networks are usually indicated by VSWR values of 1.0 to 2.0 [12].

The reflection coefficient (Γ) is defined as the relative fraction of the incident radio frequency(RF) power that is reflected back due to impedance mismatching networks and is mathematically represented by Equation(6).

$$\Gamma = \frac{V^-}{V^+} = \frac{Z_{line}-Z_{load}}{Z_{line}+Z_{load}} \qquad (6)$$

where: V^- = reflected voltage, V^+ = incident voltage, Z_{line}= line impedance, Z_{load} = load impedance.

The reduction or loss of reflected power caused by a break in the line of transmission is referred to as return loss in the context of telecommunications [13]. It is calculated using Equation (7).

$$Return\ Loss = 10\log|S_{11}|^2, or - 20\log|\Gamma| \qquad (7)$$

A return loss of less than -10 dB indicates an impedance matching that is good.

III. METHODOLOGY

A. *Initial Procedure for Determination of RMSA Specifications*

The procedure for designing a conventional single element RMSA according to [6,13,] involves specifying the resonant frequency, choosing a suitable substrate material with dielectric constant, deciding on the substrate height, determining the patch dimensions and selecting a feed approach with its feed location.

The resonant frequency (f_r) considered was 3.5 GHz, looking at future wireless networks and applications.

The substrate material that is chosen for the design of the single band RMSA is a low cost substrate called flame retardant 4 (FR 4) with dielectric constant(ε_r) of 4.4, and loss tangent of 0.019.

The height (h) of the dielectric substrate is determined from Equation (8) given in [6,9] as

$$h \leq 0.3 \times \frac{\lambda_0}{2\pi\sqrt{\varepsilon_0}} \qquad (8)$$

where $\lambda_0 = \frac{c}{f_r}$

B. *Design of Rectangular Microstrip Antenna Dimensions*

The following equations were used in the determination of the RMSA dimensions:

The calculation of the patch width (W_p) was as stated in Equation 9 [6, 14].

$$W_p = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (9)$$

Calculation of the effective dielectric constant (ε_{reff}) was obtained using Equation 10.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\left(\frac{h}{W_p}\right)\right]^{-1/2} \qquad (10)$$

Calculation of the effective Length (L_{eff}) was achieved using Equation 11[5], [16].

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (11)$$

The determination of the extension length (ΔL) was achieved with Equation 12.

$$\Delta L = 0.412h\frac{[\varepsilon_{reff}+0.3]\left[\frac{W}{h}+0.264\right]}{[\varepsilon_{reff}-0.258]\left[\frac{W}{h}+0.813\right]} \quad (12)$$

Calculation of actual length of patch (L_P) was carried out from Equation 13.

$$L_p = L_{eff} - 2\Delta L \quad (13)$$

Calculation of the ground plane dimensions (length and width) were achieved using Equations 14 and 15 respectively.

$$L_g = L_p + 6h \quad (14)$$

$$W_g = W_p + 6h \quad (15)$$

C. *Determination of the Microstrip feed Line and Quarter-Wave Transmission Line Dimensions*

The computing the patch's resonant input edge resistance (R_{in}) is shown in Equation 16 [16,17].

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \quad (16)$$

The conductance of a single slot of finite width is given by [6], [9], [18] in Equations 17 as:

$$G = \frac{W}{120\lambda_0}\left[1-\frac{(K_0h)^2}{24}\right] for \frac{h}{\lambda_0} < \frac{1}{10} \quad (17)$$

The formula to compute the characteristic impedance of the quarter wave transmission line (QWT) is given in [18] as Equation 18:

$$Z_1 = \sqrt{Z_0R_{in}} \quad (18)$$

The computation of the quarter-wave feed line width is given in [6, 9, 17]. If $\frac{W_Q}{h} < 2$ then

$$\frac{W_Q}{h} = \frac{8e^A}{e^{2A}-2} \quad (19)$$

But if $\frac{W_Q}{h} > 2$, then

$$\frac{2}{\pi}\left[B-1-ln\left((2B-1)+\left(\frac{\varepsilon_r-1}{2\varepsilon_r}\right)+\left\{\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right\}\right)\right] \quad (20)$$

Where A is given $\frac{Z}{60}\sqrt{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)}$ and B is $\frac{377\pi}{2Z\sqrt{\varepsilon_r}}$

The summary of the design dimensions for the rectangular Microstrip Antenna (RMSA) are shown in Table 1.

TABLE I. DESIGN DIMENSIONS OF 3.5GHz SINGLE BAND EDGE FED RMSA.

Design Parameters	Values
Patch dimensions:	
Length (L_p)	20.22 mm
Width (W_p)	26.08 mm
Dielectric constant (ε_r)	4.4
Substrate height (h)	1.60 mm
Patch thickness (t)	0.02 mm
Ground plane dimensions:	
Length of ground plane (L_g)	29.82 mm
Width of ground plane (W_g)	35.68 mm
Feed line dimensions:	
Width of quarter wave feed section (W_Q)	0.78 mm
Width of 50 Ω transmission line (W_0)	3.10 mm
Length of 50 Ω transmission line (L_0)	7.00 mm
Length of quarter wave feed line (L_Q)	10.80 mm
Input edge impedance of the patch (R_{in})	197.28 Ω
Characteristic impedance of the feed line (Z_0)	50 Ω
Characteristic impedance of quarter wave transformer (Z_1)	99.32 Ω

The geometrical configuration of the designed 3.5 GHz RMSA is depicted in Fig. 2 developed from the calculated parameters in Table 1.

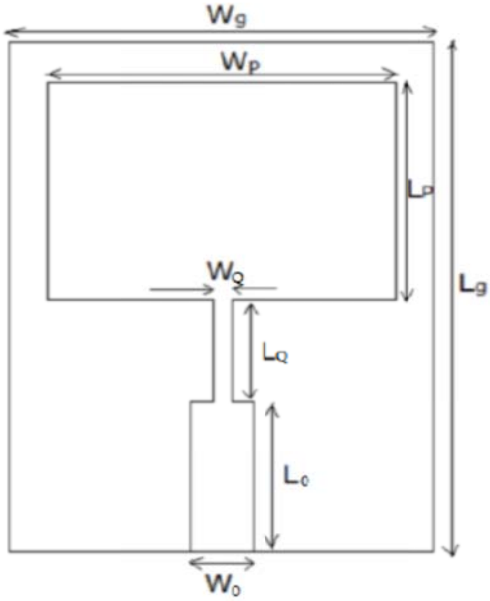

Fig.2. *Geometry of the designed antenna*

The designed single element edge fed 3.5GHZ RMSA in Computer Simulation Technology (CST) microwave studio is shown in Fig. 3.

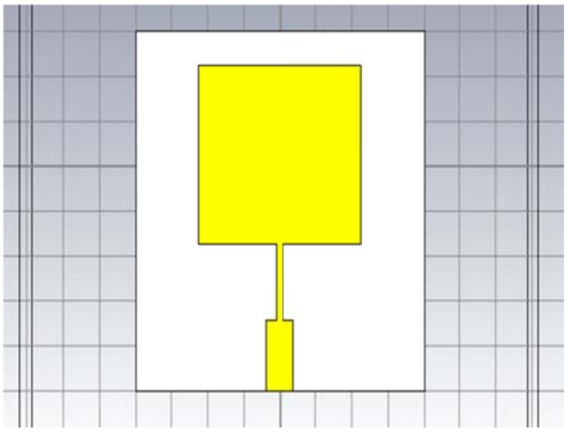

Fig. 3. *Designed antenna using CST MWS version 2021 software.*

IV. RESULTS AND DISCUSSION

A. Results

CST microwave studio is used to evaluate the RMSA performance parameters such as return loss, resonant frequency, bandwidth and gain. The simulation results for the single element RMSA are presented in the succeeding subsections.

1) Return Loss for single element RSMA

The variation of the return loss with frequency for the single element RMSA is shown in Fig. 4. The simulation result gives a return loss of -31.0dB at a resonant frequency of 3.5GHz.

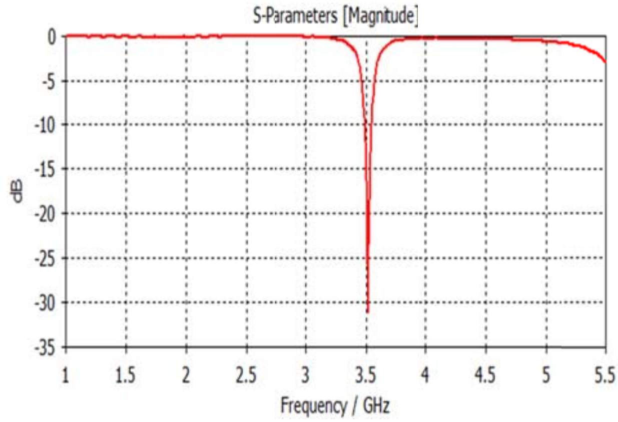

Fig.4. *Return loss plot of single band antenna at 3.5 GHz*

2) Voltage Standing Wave Ratio (VSWR)

The VSWR versus frequency plot for the designed single element RMSA is shown in Fig.5.

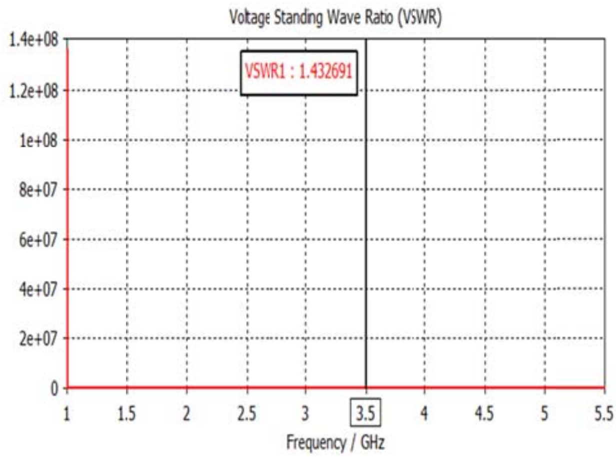

Fig. 5. VSWR of the single band RMSA at 3.5 GHz

The simulation result shows a VSWR value of 1.43 at the resonant frequency of 3.5GHZ.

3) Gain of a single element RSMA

Fig.6 shows the simulated three dimensional (3D) gain of the single element RMSA. The gain attained at 3.5GHZ is 6.6dBi as shown in Fig. 6.

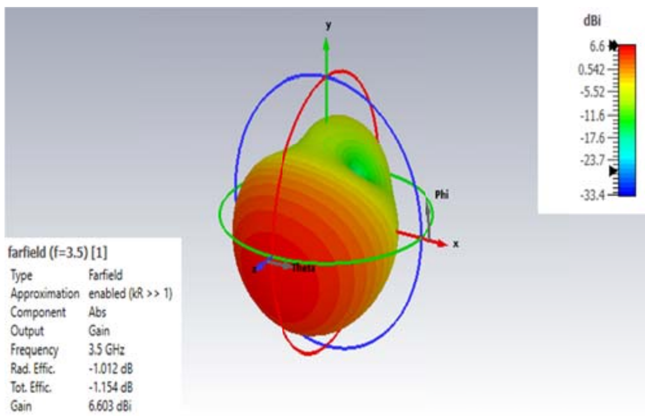

Fig. 6. Gain of 3.5 GHz single band antenna

B. Discussions

The summary of the simulation results showing the antenna characteristics (resonant frequency, return loss, VSWR and 3D gain) is shown in Table 2.

TABLE II. SUMMARY OF SIMULATIONS RESULTS

Number of Element	Resonant Frequency (GHz)	Return Loss (dB)	VSWR	3D Gain (dBi)
Single	3.5	-31.0	1.43	6.6

Based on Table 2, the designed single element RMSA resonated at the designed operating frequency of 3.5GHZ. This indicates that the designed antenna is functioning properly since it resonates at the design frequency of 3.5GHZ.

The return loss of -31.0dB for the single element antenna is a good value since it is below or less than the minimum specified -10.0dB for good MSA design. Also the return loss of -31.0dB signifies that minimum power is reflected from the patch antenna to the source input port.

The VSWR of 1.43 is within the specified limit of $1 \leq VSWR \leq 2$ for good impedance matching network.

V. Conclusion

A rectangular microstrip antenna resonating at3.5 GHzwas designed in this paper. The antenna consists of a rectangular patch, substrate and ground plane and a microstrip feed line. The patch was designed on an FR-4 epoxy substrate with dielectric constant (ε_r) of 4.4, thickness (h) of 1.6 mm and ground plane with designed dimensions of 29.82mm×35.68 mm. The substrate had a dimension of 29.82mm x 35.68mm x 1.6mm when simulated on CST Studio. The simulation results obtained showed that the designed single element RMSA resonated at 3.5GHZ with good antenna performance parameters and is suitable for 5G applications, rural broadband services [19].

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