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BROADBAND MICROSTRIP ANTENNA FOR 2G/3G/4G MOBILE BASE STATION APPLICATIONS

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Abstract: *— In this work, a staircase patch microstrip antenna with slots is proposed to cover the 2G/3G/4G cellular mobile base station bands, when the antenna is excited with a transmission line, creates several modes these modes are composite to obtain a large bandwidth. The proposed antenna operates in the band from 0.86 GHz to 4.78 GHz with an impedance bandwidth of 138%. The use of staircase patch antenna is to achieve more attractive performance such as wider bandwidth, better impedance matching and better radiation. Inserting different slots to the patch of the antenna to enhance the gain and return loss. The gain is obtained ranging from 2.18 dBi to 5.3 dBi. Good radiation efficiencies ranging from 70% to 97% is achieved.*

Keywords: 2G/3G/4G mobile base station; broadband microstrip patch antenna; staircase patch; return loss; voltage standing wave ratio.

INTRODUCTION

The fast growth of mobile communication systems needs both low cost and broadband antenna for base station [1]. Microstrip patch antenna is utilized for its simplicity, low profile, inexpensive to fabricate using modernistic printed circuit technology, conformable to planar and non-planar surfaces. When mounted on rigid surfaces compatible with MMIC (Monolithic Microwave Integrated Circiut) designs became mechanically robust [2]. Main operational abuse of the microstrip antennas are contain low power gain, low efficiency, high quality factor (sometimes in excess of 100), very narrow frequency bandwidth, spurious feed radiation and poor scan performance [3]. A patch antenna is made by excavation metal on one part of dielectric substrate while on the other opposite side there is a metal which constructe a ground plane [4]. There are a great number of forms of microstrip patch antennas, they were designed to match particular characteristics. Some of the common kinds are rectangular, square, and circular patches [5]. Different feeding mechanisms are used to feed the antenna such as coaxial, stripline, aperture coupling or proximity [6].The size of the microstrip patch antenna is inversely commensurate to the operating frequency of the antenna and the bandwidth of the microstrip patch antenna is directly commensurate to the substrate thickness and inversely commensurate to the square root of the dielectric constant of the substrate [7].

1. STAIRCASE PATCH ANTENNA DESIGN

The structure of the proposed staircase patch antenna is shown in the Figure (1). The antenna is printed on (FR-4) substrate of thickness h=1.542mm with relative permittivity ε_r=4.3, fed by a microstrip feed line.

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The performance of the antenna can be estimated over a sweep frequency range from 0 GHz to 5 GHz. The antenna dimensions are (120mm× 100mm× 1.542mm), and it operates at minimum frequency fmin=0.86 GHz and maximum frequency f_{max}=4.67 GHz, the center frequency is f_o =2.75 GHz, λ_0 (wavelength of the center frequency) equal to 180.01mm. Dimensions of the patch are chosen as w=61.5mm represent 0.565λ_0, L=46.5mm represent 0.258λ_0.The widths of the stairs W_1, W_2 , W_3 equal to 6.5mm, 6.5mm and 7.58mm respectively and their lengths H1, H2 equal to 2.5mm.

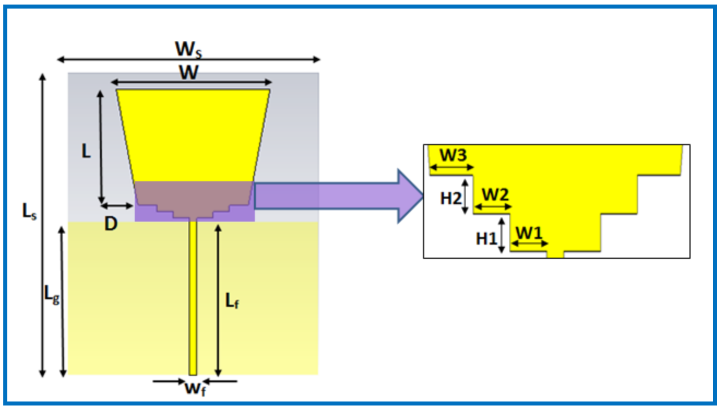

Figure 1. The structure of the proposed staircase patch microstrip antenna.

2. THE EFFECT OF DIFFERENT ANTENNA PARAMETERS ON ITS PERFORMANCE

Initial parameters of the proposed antenna give lousy performance, so that changing the antenna parameters and choosing the best values can be done, to improve its performance.

2.1. THE EFFECT OF GROUND PLAN LENGTH

Figure (2) shows the S-parameter as a function of frequency for different values of ground plane length (L_g), and fixing other values at W=61.5mm, L=46.5mm, L_f=62mm, W_f =2.5mm, W_g=100mm. From the figure it can be noticed that the curve has good bandwidth with the best return loss at L_g=61mm.

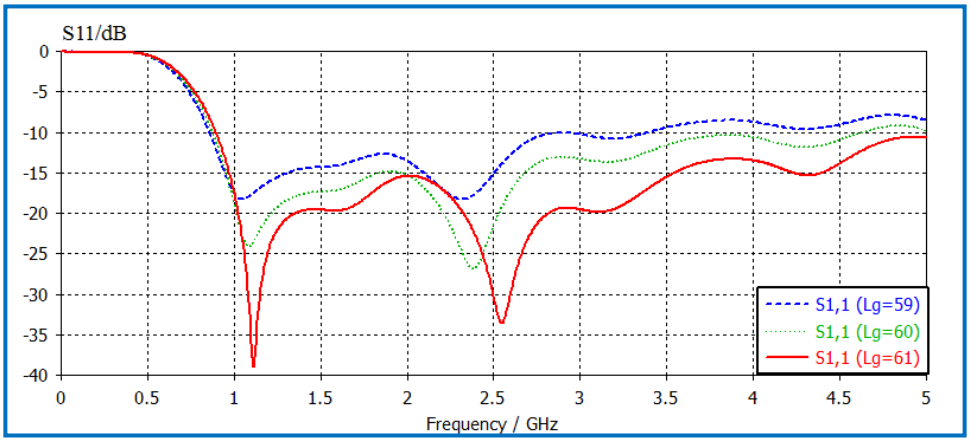

Figure 2. Simulation of S_{11} versus frequency for different values of L_g.

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2.2. THE EFFECT OF GROUND PLAN WIDTH

Figure (3) shows the S-parameter as a function of frequency for different values of ground plane width (W_g), with fixing other parameter at W=61.5mm, L=46.5mm, L_f=62mm, W_f=2.5mm, L_g=61mm. It can be seen the best value is W_g=100mm, because minimum return loss and good bandwidth can be obtained at this value.

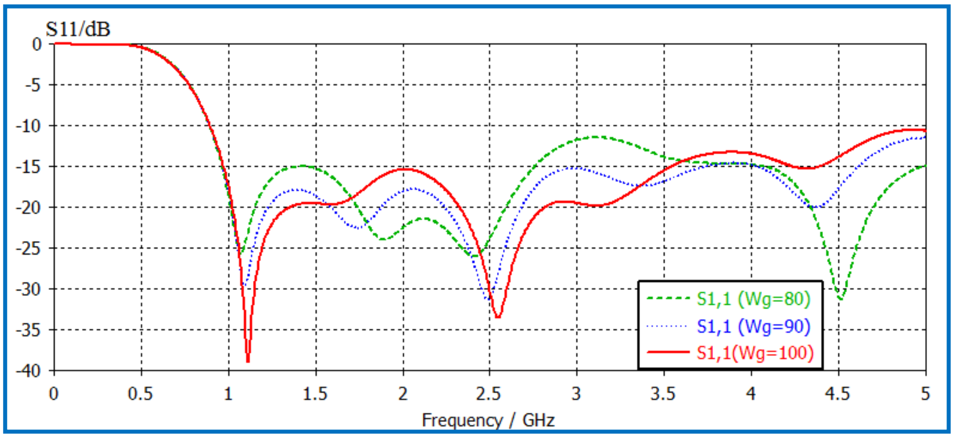

Figure 3. Simulation of S_{11} versus frequency for different values of W_g.

2.3. THE EFFECT OF FEEDER WIDTH

Figure (4) presents S-parameter for different values of feeder width (W_f), and fixing other parameters at W=61.5mm, L=46.5mm, L_f=62mm, L_g=61mm, W_g=100mm. The optimum value is W_f=3 because it gives minimum return loss at first resonance frequency and at second resonance frequency. First resonance frequency f=1.06 GHz has return loss equal to -39.45 dB, second resonance frequency f=2.4 GHz has return loss equal to -32.625 dB.

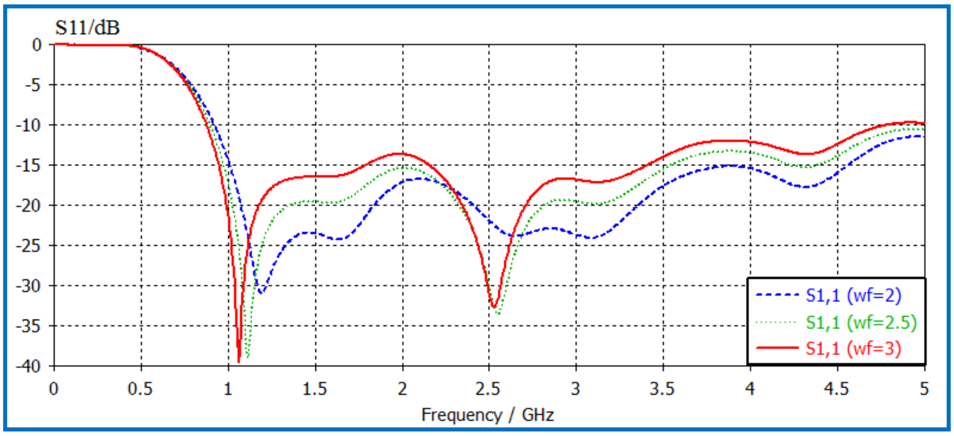

Figure 4. Simulation of S_{11} versus frequency for different values of W_f.

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2.4. THE EFFECT OF FEEDER LENGTH

Figure (5) illustrates S-parameter of the proposed antenna by varying the length of the feeder (L_f), and fixing other values at W_f=3mm, W=61.5mm, L=46.5mm, L_g=61mm, W_g =100mm. The optimum value of feeder lenght is L_f=62.5mm, because it gives good impedance matching better than other values at same bandwidth.

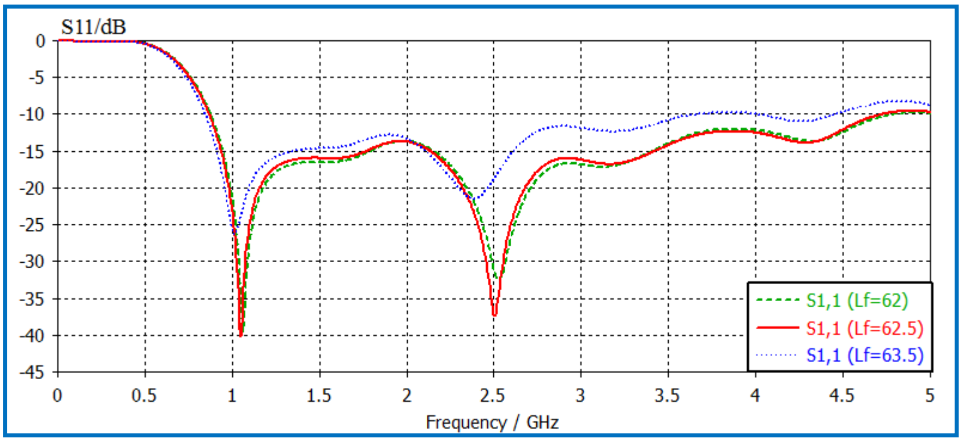

Figure 5. Simulation of S_{11} versus frequency for different values of L_f.

The parameters of the optimized staircase patch are shown in Table 1.

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Table 1. Optimal parameters of the staircase patch antenna.

Parameter	Value	Description
L_s	120mm	Substrate length
W_s	100mm	Substrate width
L_f	62.5mm	Feeder length
W_f	3mm	Feeder width
L_g	61mm	Ground plan length
W_g	100mm	Ground plan width
W	61.5mm	Patch width
L	46.5mm	Patch length
D	8.66mm	The horizontal distance that is cut from the patch

The performance of the microstrip patch antenna can be further improved, by inserting multiple slots with different shapes and dimensions on the patch, because a slot is easy way to realize the redistribution of surface currents. Design procedure for inserting the slot is to choice the best position that has minimum current distribution along the patch, after that it can be used as the proper slot with initial parameters, by optimization process, it can be chosen to achieve the best values that enhance the antenna performance. Figure (6) shows the proposed staircase patch antenna with slots and the dimensions of each slot in the patch.

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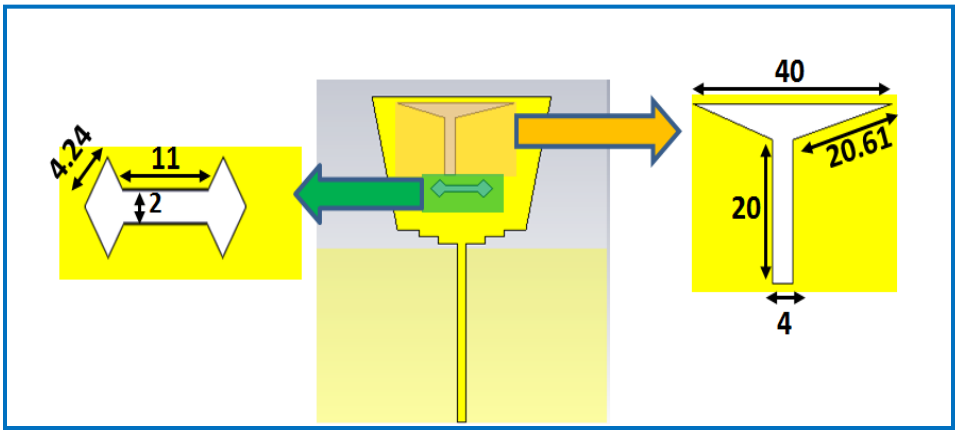

Figure 6. The proposed staircase patch antenna with slots.

Figure (7) shows the influence of slots on the return loss, it is observed that without the slot there exist two poorly matched resonances at 3.1GHz and 4.1GHz. Introducing of multiple slots into the patch improve the input impedance matching, at 3.1GHz the return loss is improved from -16 dB to -39 dB and at 4.1 GHz is improved from -12 dB to -16 dB.

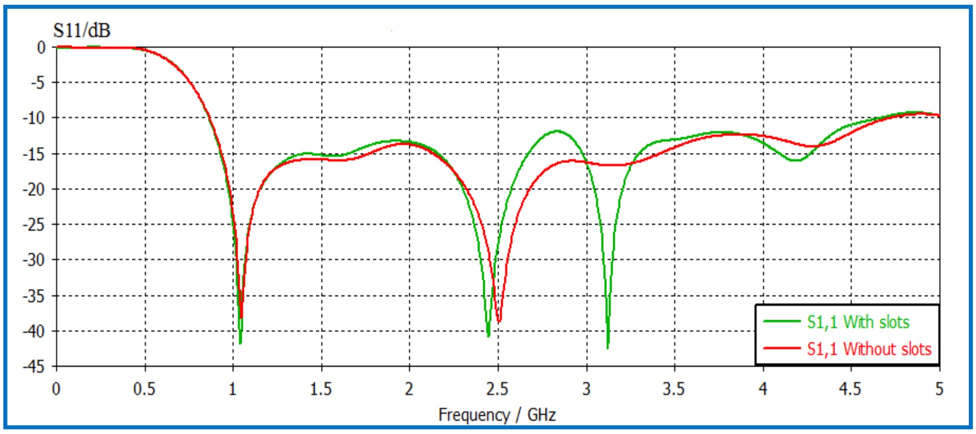

Figure 7. Simulation of S_{11} versus frequency for the staircase patch with and without slots.

The proposed staircase patch antenna with slots is fabricated. Figure (8) shows the photograph of the fabricated antenna.

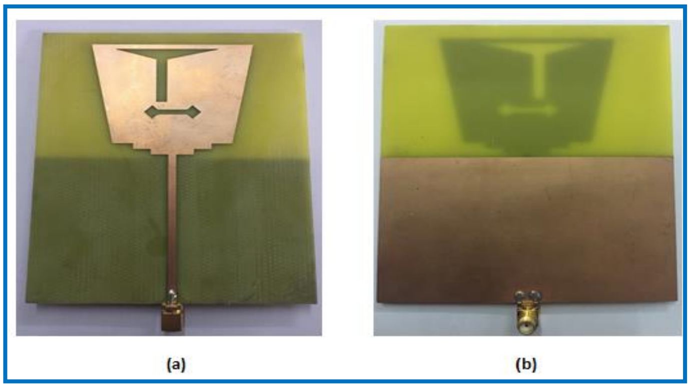

Figure 8. Photograph of the fabricated staircase patch antenna, (a) Front view, (b) Back view.

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3. CHARACTERISTICS OF STAIRCASE PATCH ANTENNA WITH SLOTS

3.1. S-PARAMETER

The fabricated staircase patch antenna is tested by using VNA (Vector Network Analyzer). Figure (9) shows the simulation and measurement S-parameter of the proposed antenna. Acceptable result between the measurement and simulation can be obtained, except from 3.5 GHz to 3.88 GHz became out of the proposed band. The variation in the measured and the simulated response is primarily due to fabrication errors, soldering of SMA connector or ambient environment which the measurement are carried out.

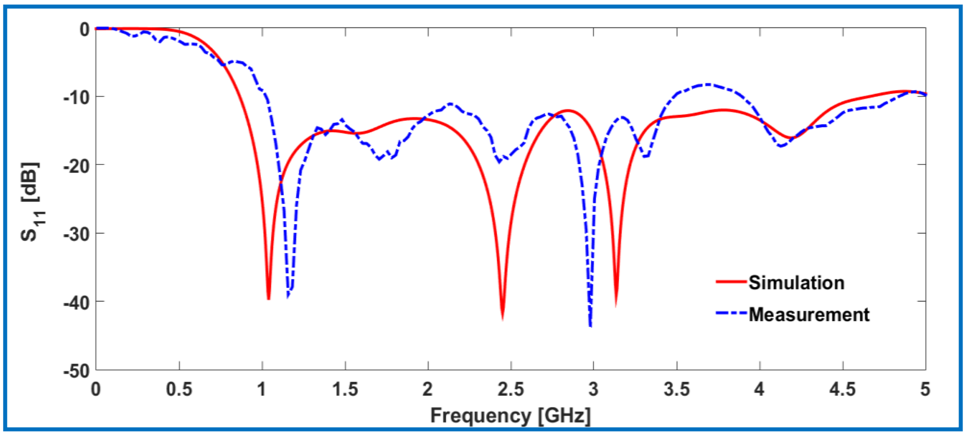

Figure 9. Simulation and measurement of S-Parameter for the staircase patch antenna with slots.

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3.2. VOLTAGE STANDING WAVE RATIO (VSWR)

The antenna has smaller VSWR which means it is matched to the transmission line and can be considered the best antenna. The minimum VSWR is 1, VSWR =1 means no power reflected from the antenna, for practical applications VSWR less than or equal to 2 can be taken into account [8]. Figure (10) shows VSWR for different frequencies, it is clear that from the curve, the value of VSWR is less than 2 at all frequencies of the band and the best VSWR can be obtained at resonance frequencies, at f=1GHz VSWR =1.03, at f= 2.4GHz VSWR = 1.02 and at 3.1GHz VSWR =1.

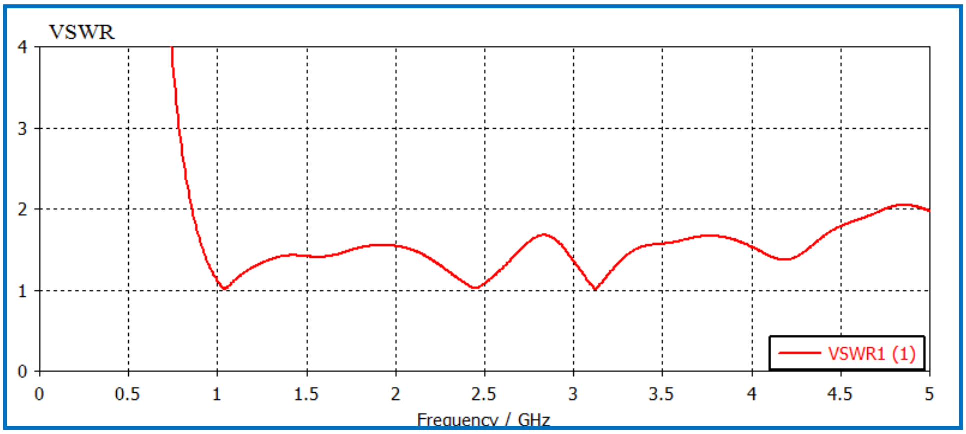

Figure 10. Simulation of VSWR versus frequency of staircase patch antenna with slots.

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3.3. ANTENNA GAIN

Figure (11) shows the effect of slots on the gain of the antenna, inserting slots to the patch also enhanced the gain of the antenna over a wide range of the frequencies. From 0.86 to 2 GHz the gain didn't change, from 2 GHz to 4.2 GHz the gain improved significantly, but for frequency range from 4.3 GHz to 4.8 GHz the gain slightly decreased.

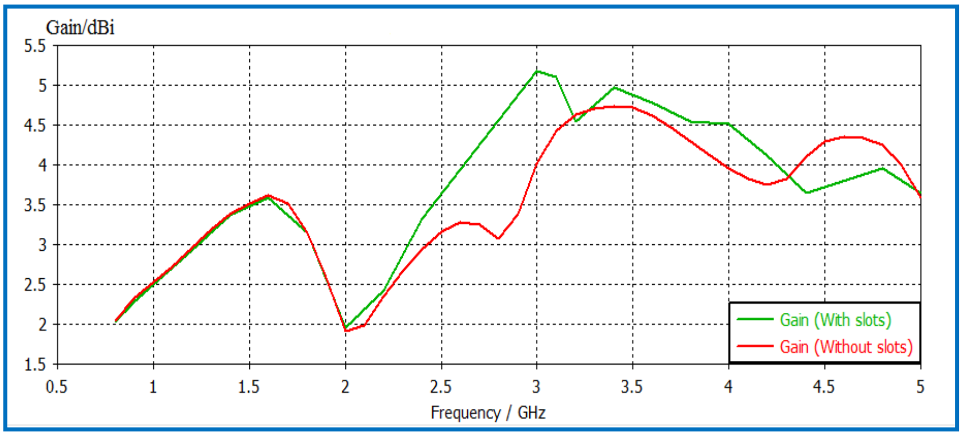

Figure 11. The gain of the staircase patch antenna with and without slots.

3.4. INPUT IMPEDANCE

From Figure (12), It can be observed that the relative impedance matching between the feed line and the antenna, and the real part of the impedance at resonance frequencies (1GHz, 2.4GHz, 3.1GHz) are (48.9Ω, 47.5Ω, 48.15Ω) respectively, while imaginary part of the impedance at resonances frequencies are (-5.3Ω, -1.3 Ω, -1.7Ω) respectively.

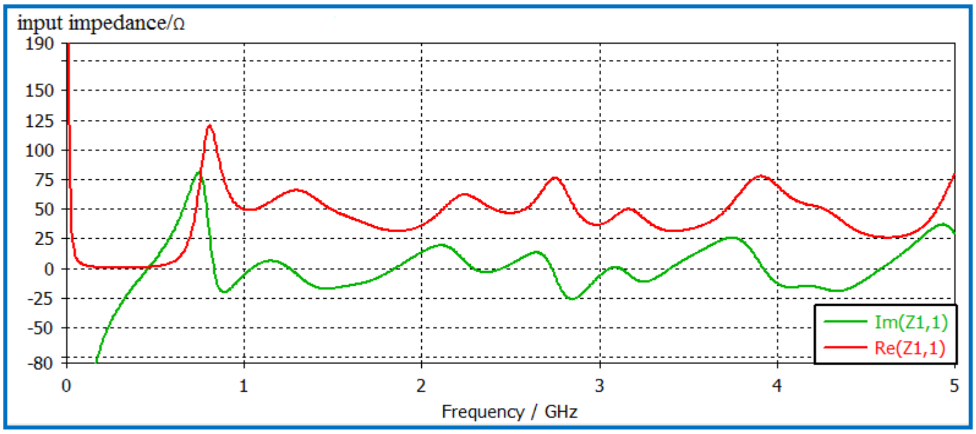

Figure 12. Real part and imaginary part of input impedance against frequencies for staircase patch antenna with slots

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3.5. CURRENT DISTRIBUTION

The current distribution of the proposed staircase patch antenna with slots can be seen in Figure (13). Figure (13) offers the concentration of current in the antenna at frequencies 1GHz, 2.4 GHz, 3.1GHz and 4 GHz. Figure (13)a, shows the current distribution at the frequency 1GHz, from the figure it can be noticed that the maximum current is 54.8 A/m and most concentration of the current is on the feed line. Figure (13)b, shows the current distribution at frequency 2.4GHz, from the figure it can be noticed that the maximum current equal to 66.1 A/m and most concentration of the current on the feed line and around the sides of the upper slot. Figure (13)c, shows the current distribution at the frequency 3.1GHz, from the figure it can be noticed that the maximum current is163A/m and most concentration of the current around the sides of the upper slot. Figure (13)d shows the current distribution at the frequency 4GHz, from the figure it can be noticed that the maximum current is 38.8 A/m and most concentration of the current at most parts of the feed line and around the sides of the lower slot.

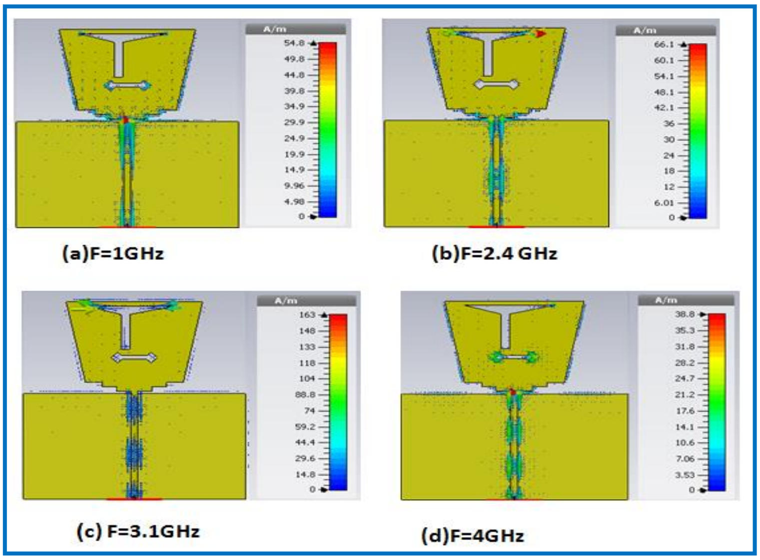

Figure 13. The current distribution of the staircase patch antenna with slots at different frequencies.

3.6. 3-D RADIATION PATTERN

The 3-D radiation pattern of the staircase patch at different frequencies is shown in Figure (14). The directivity over the phi and theta angels for the proposed antenna can be shown by these plots. For the frequencies 1GHz, 2.4GHz and 3.1GHz, the maximum directivity is 2.59 dBi, 3.69 dBi and 5.96 dBi respectively. The radiation pattern for frequencies 1GHz and 2.4GHz are omnidirectional radiation pattern and for 3.1GHz is quasi omnidirectional radiation pattern.

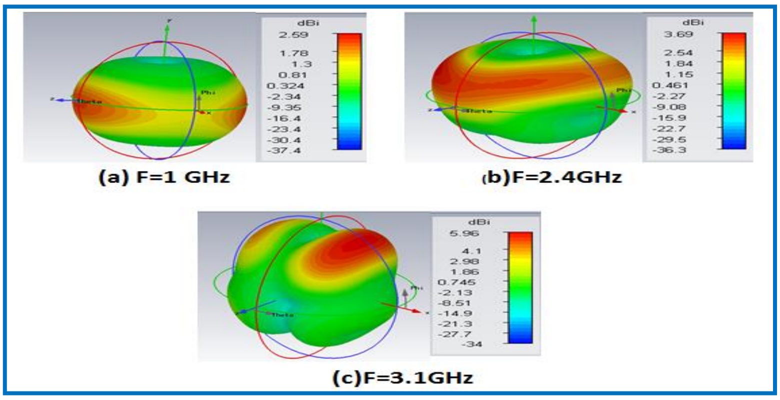

Figure 14. The 3-D radiation pattern of the antenna for different frequencies.

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3.6. E-PLANE, H-PLANE RADIATION PATTERN

Figure (15) shows the E-plane and H-plane for the frequencies 1GHz, 2.4GHz and 3.1GHz. Figure (15) a shows E-plane and H-plane for 1GHz, E-plane has main lobe magnitude equal to 2.59 dBi, main lobe direction is -176degree, angular width (3dB) is 81.2 degree, H-plane has main lobe magnitude equal to 1.26 dBi, main lobe direction is -7degree, angular width (3dB) is 89 degree. Figure (15)b shows E-plane, H-plane for 2.4 GHz, E-plane has main lobe magnitude equal to 3.23 dBi, main lobe direction is -20degree, angular width (3dB) is 66 degree, H-plane has main lobe magnitude equal to 3.23 dBi, main lobe direction is 147degree, angular width (3dB) is 53 degree, side lobe level angular width (3dB) is -7.6dB. Figure (15)c shows E-plane, H-plane for 3.1GHz, E-plane has main lobe magnitude equal to -0.095 dBi, main lobe direction is 46degree, angular width (3dB) is 47 degree, side lobe level is -1.3dB, H-plane has main lobe magnitude equal to 5.99 dBi, main lobe direction is 57degree, angular width (3dB) is 37 degree, side lobe level is -1.6dB..

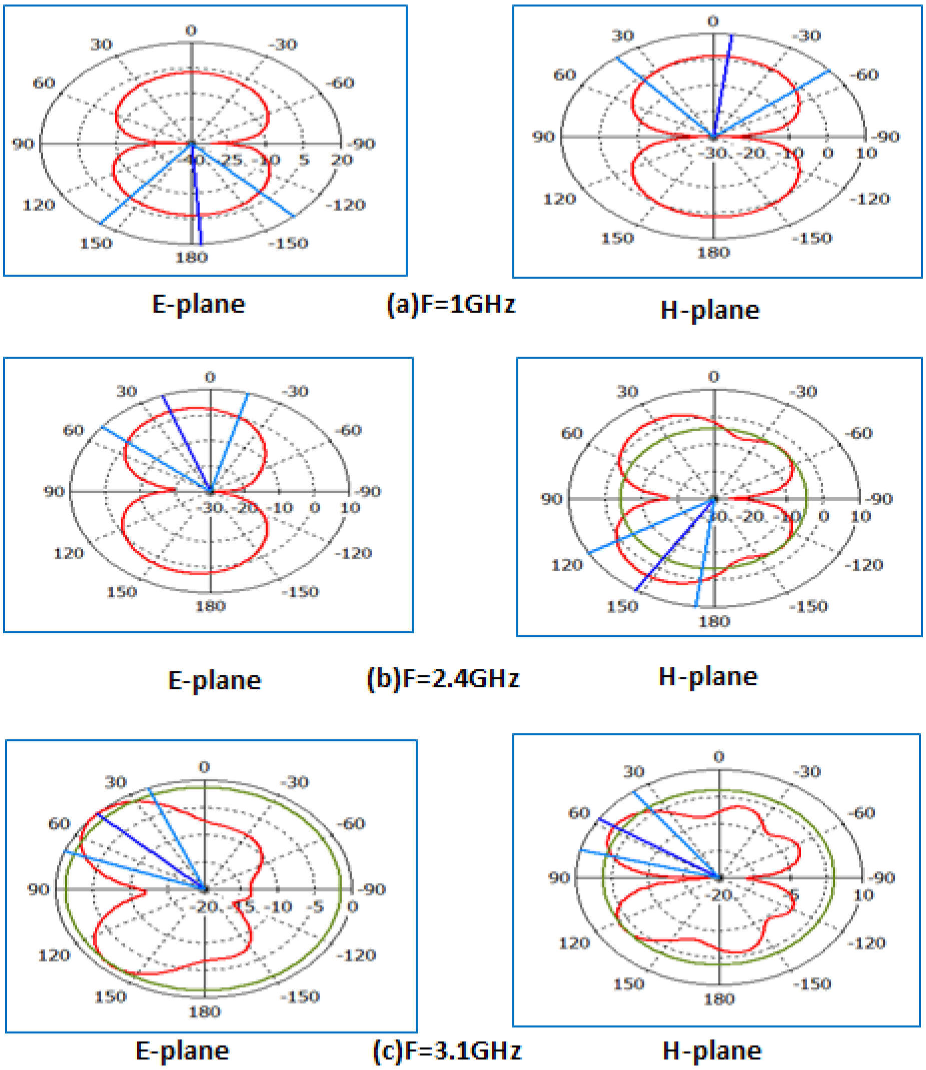

Figure 15. E-Plane, H-Plane of staircase patch antenna with slots at different frequencies.

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3.7. GROUP DELAY

The group delay of staircase patch antenna with slots is shown in the Figure (16). It can be observed that group delay is less than 2ns in the most of the band, which means minimum distortion occurs on the pulse, because the group delay is constant in almost all the ranges of frequencies.

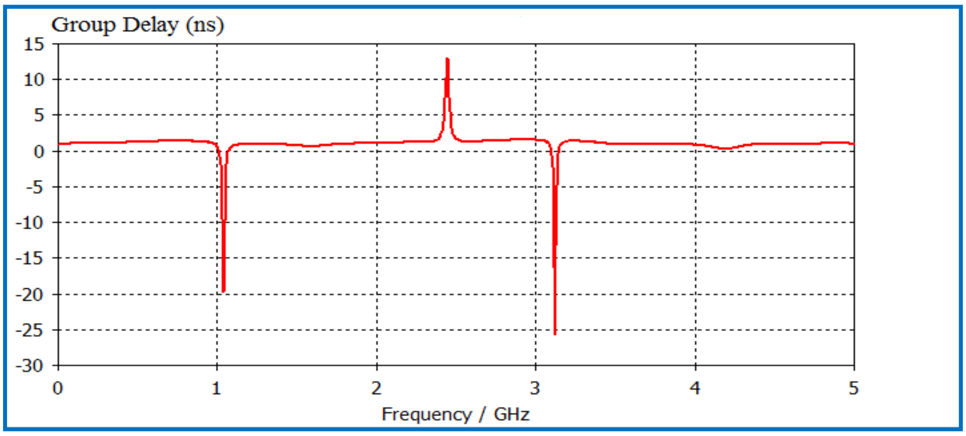

Figure 16. The group delay versus frequency for staircase patch antenna with slots.

Table 2 which is shown below, illustrates a survey comparison between this work and the work in the reference [9]. From Table 2, it can be noticed that the antenna in the reference [9] covers three separated band, but this work covers a wider bandwidth equal to 3.92 GHz, with acceptable gain ranging from 2.18 dBi to 5.3 dBi, and also can be made a size reduction of the antenna by 42.86% as compared to the antenna in reference [9].

Table 2. Comparision between this work and work in the reference [9].

Refrences	**Bandwidth (GHz)**	**Gain (dBi)**	**Dimensions(W×L×H)mm^3**
Ref [9]	(0.68-0.821)&(0.86-0.96) (1.56-2.15)&(2.13-2.495)	(0.89-2.47)	(230×176×0.8)
This work	(0.86-4.87)	(2.18-5.3)	(100×120×1.542)

CONCLUSION

A staircase broadband microstrip patch antenna operates in the 2G/3G/4G mobile base station has been proposed. The key of the design is the use of a stepped patch to enhance the matching between the antenna and the transmission line. The proposed antenna operates in the frequency range from 0.86 GHz to 4.78 GHz, and gives gain ranging from 2.18 dBi to 5.3 dBi. The antenna is designed using multiple slots configuration, with optimization techniques implemented on it to achieve the best possible desired results. The proposed antenna with slots is fabricated and tested practically using MS46-42A Vector Network

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Analyzer (VNA), and the result of S11 is compared with simulation result, it is observed that the practical result agree with simulation result and a slight difference is attributed to the fabrication errors.

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