An Insight into Impact of Partial Ground and Dual Trapezoidal Slots on Bandwidth and Gain considerations for a Microstrip Antenna Array for WiMax Application

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Abstract

In this work, design and analysis of microstrip patch antenna is carried out. A (2 X 1) antenna array is considered, with dimensions (W x L) as 35.11 mm x 27.13 mm. The dielectric substrate is taken to be FR4 epoxy with dielectric constant as 4.3 and loss tangent of 0.02. Dual trapezoidal slots are introduced to improve the gain considerations for the considered antenna array. The simulations are carried out and it is observed that the gain is improved. As a second stage in the work, to improve the bandwidth of operation for the dual trapezoidal antenna array, the concept of partial ground is taken into consideration. The simulations are carried in HFSS. It is found out that the introduction of partial ground improved the bandwidth of the antenna structure considered while preserving the gain to the maximum extent possible. The gain was found to be 7.0875 dB with centre frequency 2.4020 GHz. The frequency range below -10dB for the considered antenna array structure with partial ground was around 2.3 GHz to 2.6 GHz. This range is utilized in the WiMax application which covers the frequency ranges (2.3 GHz to 2.4 GHz) and (2.496 GHz to 2.690 GHz).

1. Introduction

The demand for wireless systems made the industry to make many new antenna structures suitable for working in the range of single band to multiple bands. Mircostrip antennas and printed antennas were two favorites in this area at that time [1]. With the advantage of having extremely low profile, less cost and ease of fabrication, the microstrip patch antennas gained much importance in the wireless industry. Some of the applications are the mobile communications, Radio frequency identification systems, etc. [2]. These antennas are usually of thin scale and are easily compatible in the use of integrated circuits. Because of the vast research carried out in the recent years, several commercial applications of the microstrip patch antennas came into existence. The usual form of a microstrip patch antenna is a patch being placed on a grounded dielectric substrate [3]. Quarter wavelength and half wavelength rectangular patch antennas are most widely used. But later on other configurations such as triangular, circular and ring patches also came into existence [4]. However disadvantages circulated around these antennas. Extremely narrow bandwidth and less gain are some of them. Many researches are being done to improve the gain of the patch antennas [5]. This is implemented using different antenna sizes, shapes, parameters, designs and materials [6-9]. With the advancement of technologies it became necessary to decrease the size of the antenna. Slots are generally preferred when size of the antenna is a constraint. Different shapes of slots were also proposed over the years [10-12]. In particular, the use of dual trapezoidal slots is discussed in [10]. To meet the requirements on the bandwidth constraints, the use of partial ground were introduced [15-18].This is done to increase the efficiency levels of the wireless systems.

In this paper, a (2 X 1) microstrip patch antenna array is considered. Mirrored trapezoidal slots are cut on the patches to improve the patch antenna characteristics. The antenna is designed and simulated using the HFSS software.

2. Antenna Design Structure

In order to overcome the limitations seen in single antenna, antenna arrays are proposed. Antenna arrays are group of similar antennas placed in particular geometry. This is done to enhance the radiation properties to the point of interest. The overall gain is said to be improved. The interference problem can be suppressed to a minimum level. To determine the signal; which is of interest and cancel out all other signals [13]. Therefore antenna arrays provide significant advantages when compared to single antenna structure.

For the proposed antenna, a ground plane of (W x L) 90 mm and 50 mm is considered. FR4 epoxy is taken to be the dielectric substrate with permittivity of '4.3' and loss tangent of '0.02'. The design considerations regarding the length and width of the patch are considered from the general rectangular patch antenna equation for length and width discussed in [14]. Since, the idea is to design an antenna for WiMax application, which covers ranges (2.3 GHz to 2.4 GHz) and (2.496 GHz to 2.690 GHz), the width and length are considered by substituting respective values in the empirical formula for rectangular patch antenna given in [14]. Therefore a (2 X 1) patch antenna array is designed with two rectangular microstrip patch antennas, each of dimensions (W x L) 35.11 mm and 27.13 mm. These dimensions yielded an overall antenna design which would resonate in the WiMax frequency range. The height of the substrate is '1.6 mm'.

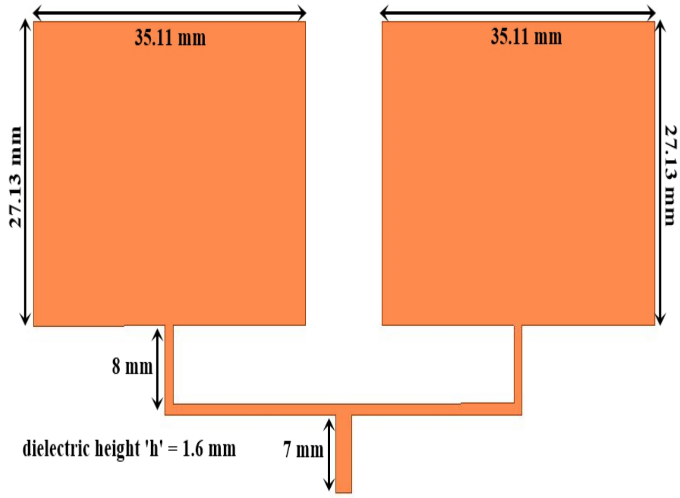

Figure 1 A conventional 2 X 1 microstrip patch antenna structure

When etched in a desired manner, slots are made to be formed on the radiator. Slots which are made on the radiating patch make the excited surface currents to wander, which leads to decrease in the resonant frequency of the antenna. As a result, the antenna is minimized, when it is compared to a patch antenna without slots. Also, introduction of slots made the patch antenna to work in broader frequency ranges [11]. Now, for the two patch antennas, dual trapezoidal slots are cut. In general, a trapezoid has two parallel sides and two non-parallel sides. Among the two parallel sides, one side form the long base and the other side form the short base. The other two non-parallel sides are called as 'legs'. To achieve good impedance matching, the parameters of this trapezoid structure, namely 'p', 'q', 'r' and 's' are important. Firstly, the 'q' which forms the short base is considered for an appropriate length, and 'p' which forms the long base is adjusted for different lengths (starting from 20mm and thereby decreasing 1mm in length). For each instance after short and long base are fixed, the side legs 'r' and's' attached which completes the trapezoid structure. The structure is tuned for different 'p' lengths till proper impedance matching was achieved. Therefore, the optimized values for the long base were '20 mm' and the short base was found to be '7 mm'. The side legs which form the non-parallel sides are '6 mm' on both sides. The trapezoidal structure is shown in figure 1.

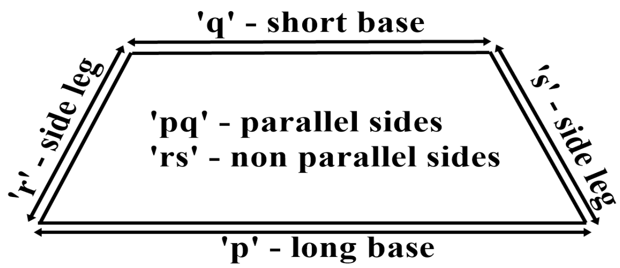

Figure 2 Trapezoid structure

The proposed rectangular microstrip patch antenna with dual trapezoidal slots is shown in the figure 3.

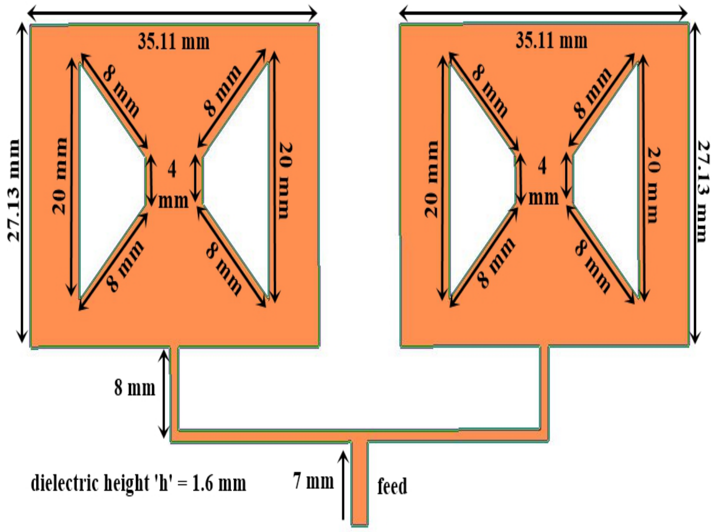

Figure 3 Patch antenna structure with dual trapezoidal slots

Feeding for the proposed antenna is given by a microstrip transmission line having a characteristic impedance of '50 Ω'.

3. Findings from the Antenna Array And Slotted Antenna Array

3.1 For 2 X 1 Patch Antenna Array

Firstly, the properties of the conventional 2 X 1 patch antenna array are studied. The 2 X 1 patch antenna is constructed simulated using the HFSS simulation software. The findings for simulated S11 are plotted as shown in the given figure 4 below.

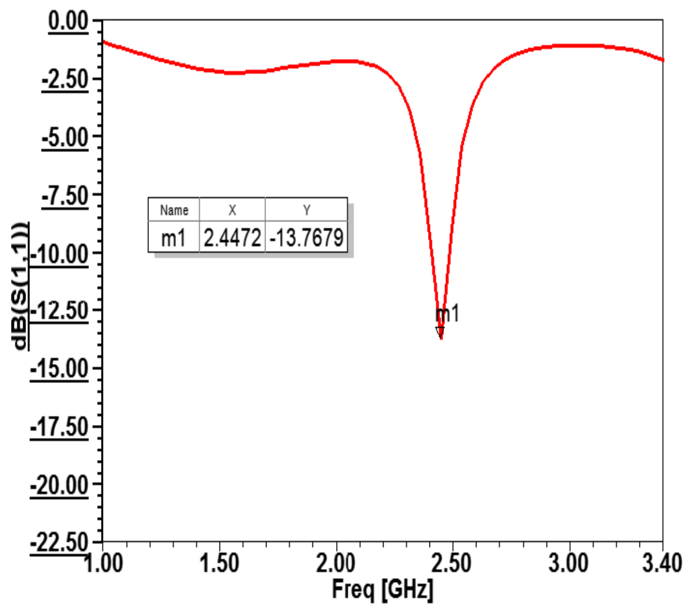

Figure 4 The simulated S11 for the conventional 2 X 1 microstrip antenna

The simulated S11 for the conventional 2 X 1 microstrip antenna showed -13.7679 dB for a centre frequency of 2.44 GHz. The bandwidth was found to be "0.0757 GHz" with the frequency ranges of 2.4065 GHz to 2.4822 GHz.

The VSWR is calculated to be 1.5155 at the frequency of 2.44 GHz and the gain of the antenna array is measured to be 3.8 dB. The reflection coefficient is found out to be 0.20. It is calculated from the relation between reflection coefficient and VSWR. The reflected power and mismatch loss is calculated to be 4.2% and 0.19 dB. The VSWR and gain plots are given in the figure 5 and figure 6 below.

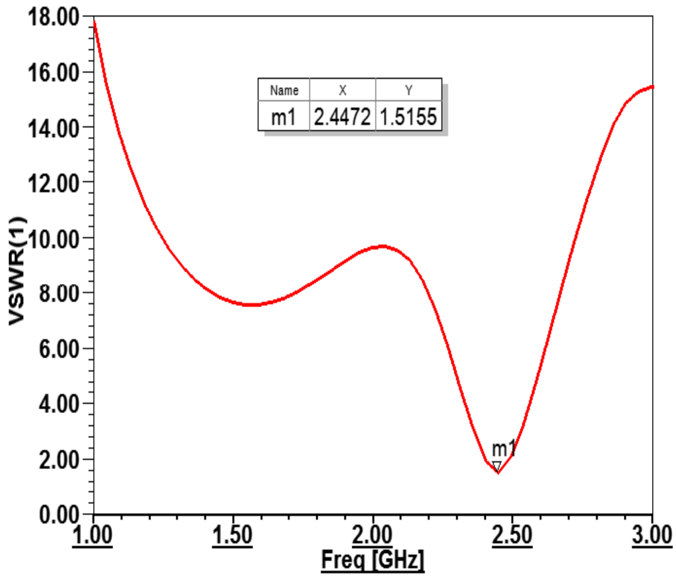

Figure 5 VSWR plot for the conventional 2 X 1 microstrip antenna

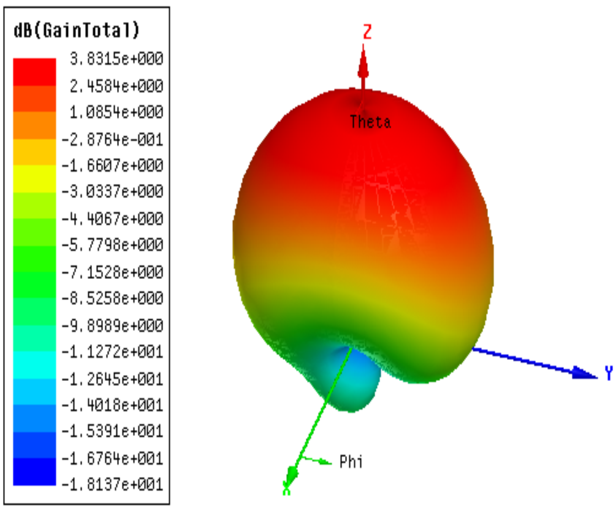

Figure 6 The gain plot for the conventional 2 X 1 microstrip antenna

3.2 For Dual Trapezoidal Slot Antenna Array

On the other hand, for the microstrip antenna array with dual trapezoidal slots, the simulated S11 is calculated to be -28.48 dB with centre frequency at 2.31GHz. The bandwidth of this antenna array is measured to be 0.1244 GHz with the frequency ranging from 2.25 GHz to 2.38 GHz. The S11 plot is given in the figure 7 below.

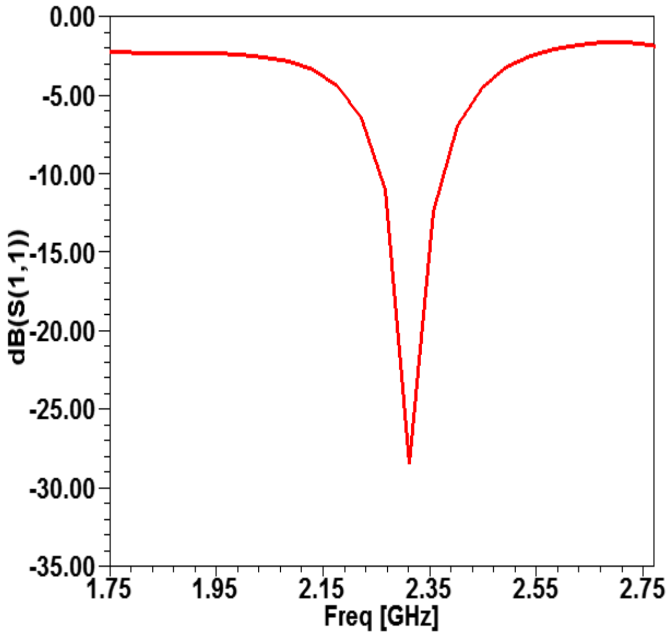

Figure 7 The simulated S11 for the trapezoidal slotted 2 X 1 microstrip antenna

Secondly, the VSWR is found out to be 1.0783 which is less than 2. The gain of the slotted antenna array is calculated and was found out be 7.83 dB. The reflection coefficient is found to be 0.04 in this case. The reflected power is 0.1% and the mismatch loss is 0.01 dB. Therefore, when compared with the conventional microstrip patch antenna, the reflected power is decreased and the mismatch loss is significantly decreased, leading to better performance of microstrip antenna with slots. The plots for the VSWR and gain are plotted in the figure 8 and figure 9 below.

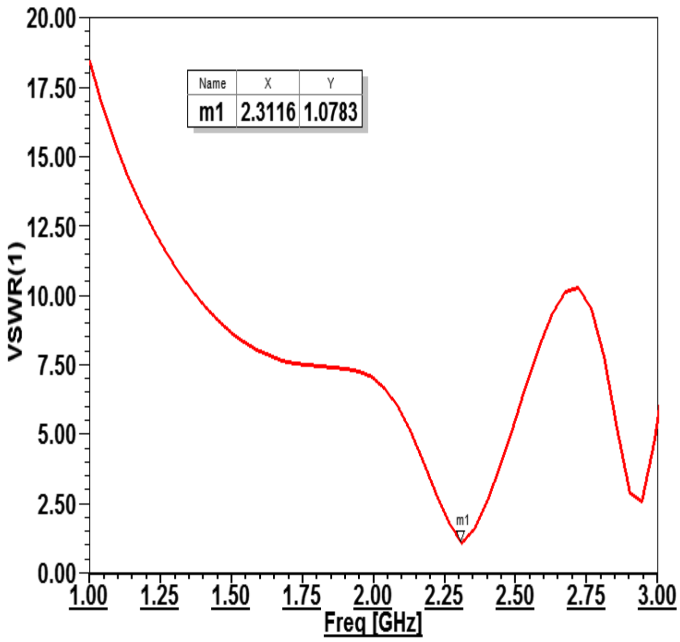

Figure 8 The VSWR plot for the trapezoidal slotted 2 X 1 microstrip antenna

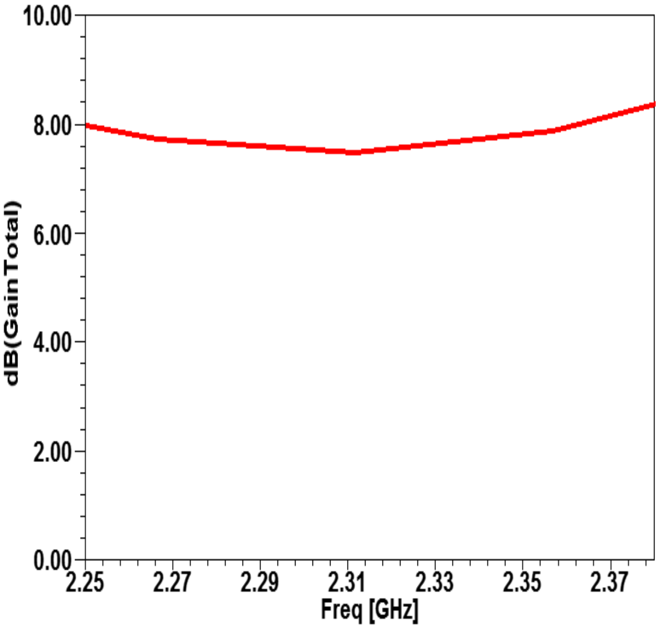

Figure 9 The gain plot for the trapezoidal slotted 2 X 1 microstrip antenna

4. Dual Trapezoidal Slot Microstrip Antenna Array with Partial Ground

It is to be noted that even though the gain of the antenna array is significantly improved to 7.83 dB when dual trapezoidal slots are used when compared to the 3.83 dB gain of conventional 2 X 1 antenna array, the bandwidth is not improved to a significant level. For achieving the wider bandwidth various antenna designs are implemented. These include waveguide horns, bi-conical antennas, etc. Several broadband monopole antennas were also discussed in this regard, but the problem is that their ground planes are said to be perpendicular to the radiating elements. This makes these antennas difficult for fabrication on printed circuit boards. Recent implementations include double sided patch antennas with modifications introduced on the ground plane [18]. To be more precise, the partial ground behaves as an element for matching the impedance that shows significant effect on the impedance bandwidth of the radiating patch antenna.

Therefore, the use of partial ground is employed to improve the bandwidth capabilities for the dual trapezoidal slotted microstrip antenna array. The antenna array structure is given in the figure 10 below. Necessary changes are made in the ground plane and cut along the symmetry of the slotted patch antenna array. The dimensions are 50 mm along the width and 45 mm along the length. These values are considered by initially choosing the entire width and length of the ground plane and thereby decreasing the dimensions (W x L) in 1mm for each instance. The dimensions of the ground plane greatly influenced the S11 parameters of the proposed antenna. Increase or decrease in the values of the width and length showed its influence on the S_{11} parameters. Therefore, the optimum value was taken to be 50 mm x 45 mm (W x L) as they showed good reflection coefficient value. The entire scenario showed improvements in the bandwidth of the dual trapezoidal slotted patch antenna array.

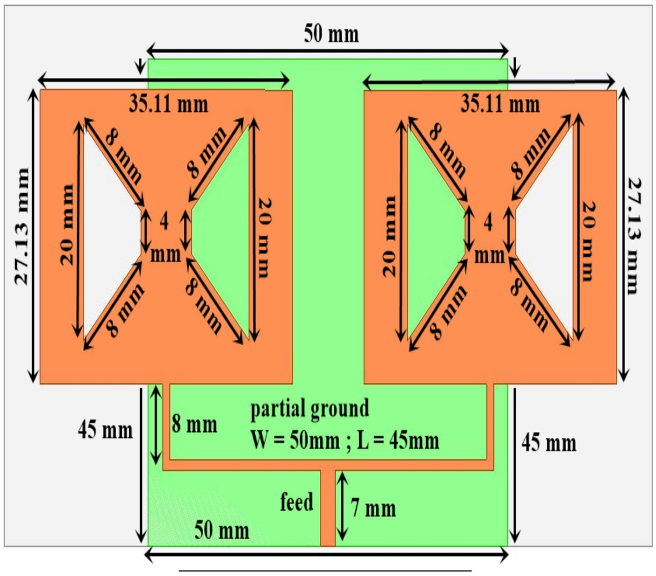

Figure 10 Dual Trapezoidal Slotted Microstrip Antenna Array with Partial Ground

5. Findings from the Proposed Antenna with Partial Ground

The simulations are carried out and firstly the S11 is calculated. It is found to be -22.5779 dB with centre frequency 2.4020 GHz. The return loss RL which is said to be equal to –S11 (scattering parameter) was above 10 dB (RL > 10 dB) in the required frequency range from 2.30 GHz to 2.6 GHz. The bandwidth is measured to be 0.3 GHz (300 MHz) with the frequency range of 2.30 GHz to 2.6 GHz. The S11 plot is given in the figure 11 as follows.

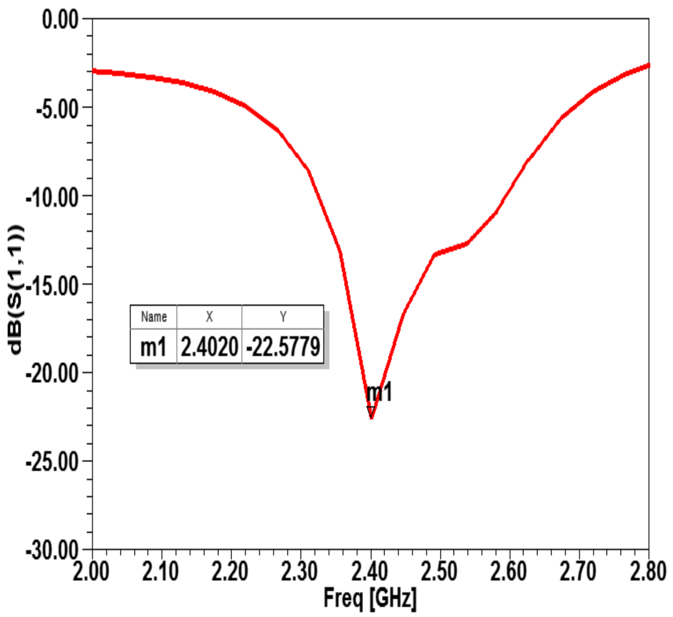

Figure 11 The simulated S11 for the proposed antenna array with partial ground

The VSWR is plotted and is found out to be 1.1606 with centre frequency 2.4020 GHz. Reflection coefficient when considering the proposed antenna is found out to be 0.07 (0.04 in case of antenna with slots). The reflected power is calculated to be 0.5% (0.1% in case of antenna with slots) and the mismatch loss is 0.02 dB (0.01 dB in case of antenna with slots). The gain was calculated and is found to be 7.0875 dB. It is to be noted that, the proposed antenna with partial ground observed significant improvement in the bandwidth while maintaining the gain to the maximum extent possible. These are given bellow as figure 12 and figure 13.

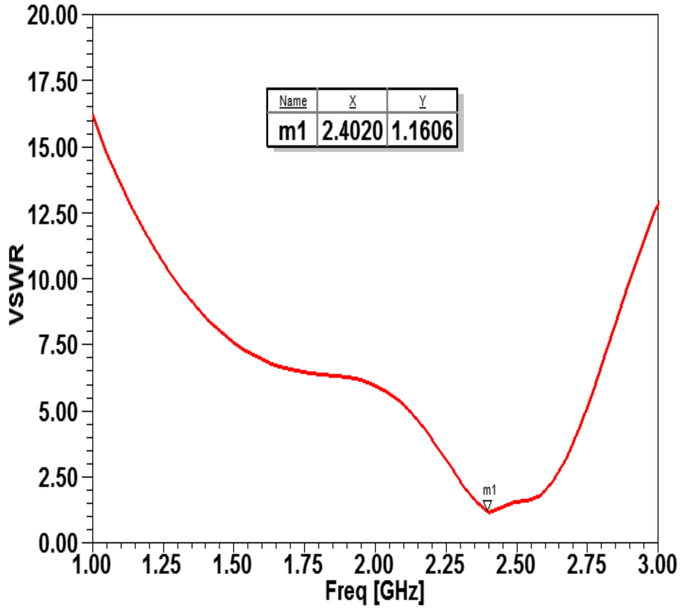

Figure 12 The VSWR plot for the proposed antenna array with partial ground

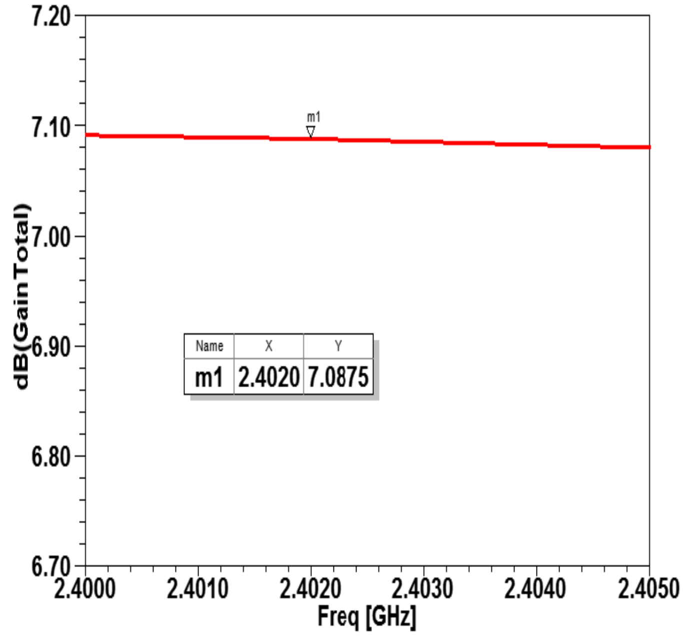

Figure 13 The 2D gain plot for the proposed antenna array with partial ground

The comparisons are carried out between the conventional 2 X 1 array, dual trapezoidal slotted array and the dual trapezoidal slotted array with partial ground with respect to simulated S11 and gain. It is given in the figure 14 and figure 15 below.

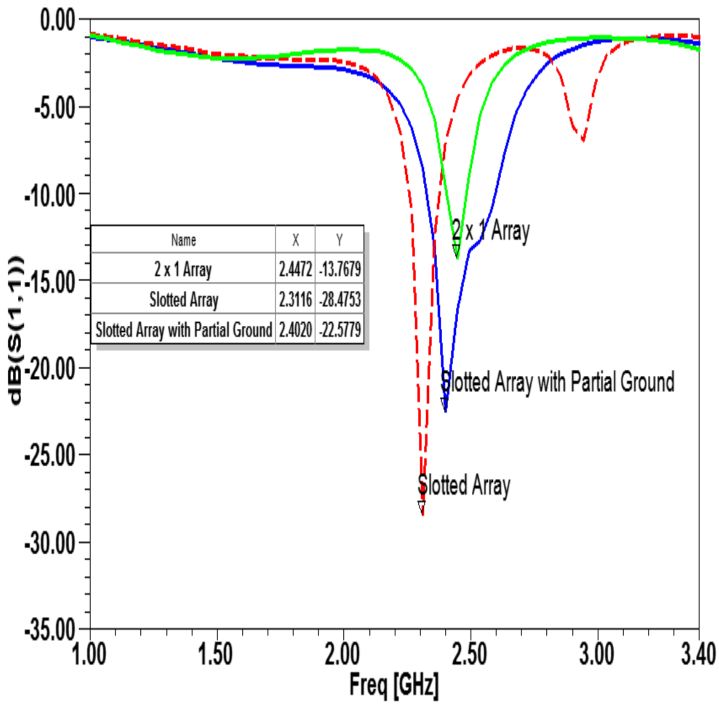

Figure 14 Simulated S11 comparison plot for the considered Antenna Array structures

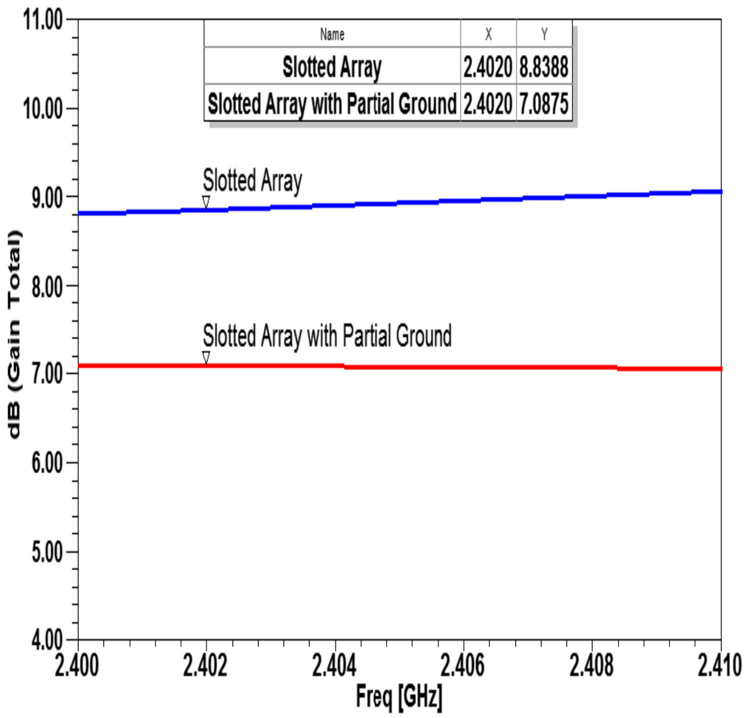

Figure 15 The 2D gain comparison plot for slotted array and slotted array with partial ground

Table 1 Comparison of Antenna parameters for the antenna structures considered

Antenna Parameters	2 X 1 Microstrip Antenna Array	Dual Trapezoidal Slot Antenna Array	Dual Trapezoidal Slot Antenna Array with Partial Ground
Frequency Range (below 10 dB)	2.4065 GHz to 2.4822 GHz	2.25 GHz to 2.38 GHz	2.30 GHz to 2.6 GHz
Bandwidth	0.0757 GHz	0.1244 GHz	0.300 GHz
Centre Frequency	2.44 GHz	2.3116 GHz	2.4020 GHz
Simulated S11 (dB)	-13.7679 dB	-28.48 dB	-22.5779 dB
Gain (in dB)	3.8 dB	7.83 dB	7.0875 dB
VSWR	1.5155	1.0783	1.1606

The fabrication is done for the proposed dual trapezoidal slotted microstrip patch antenna with partial ground. The fabricated prototype is given in the figure 16 and figure 17. The fabricated antenna with partial ground is then tested and the measured results are carried out with network analyser. These are depicted in figure 18 and figure 19 below.

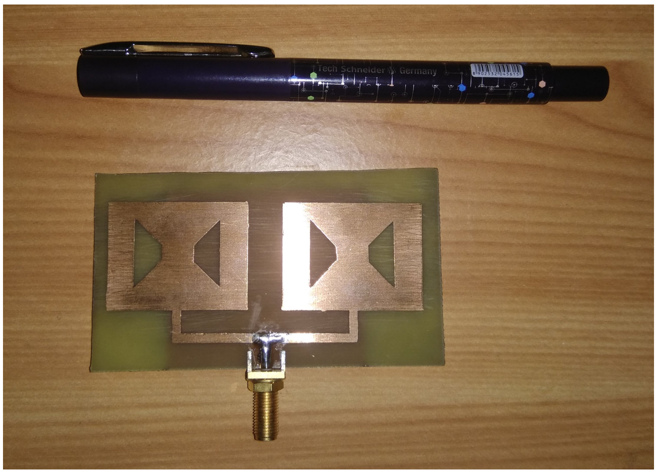

Figure 16 The Fabricated prototype of the proposed antenna; front view

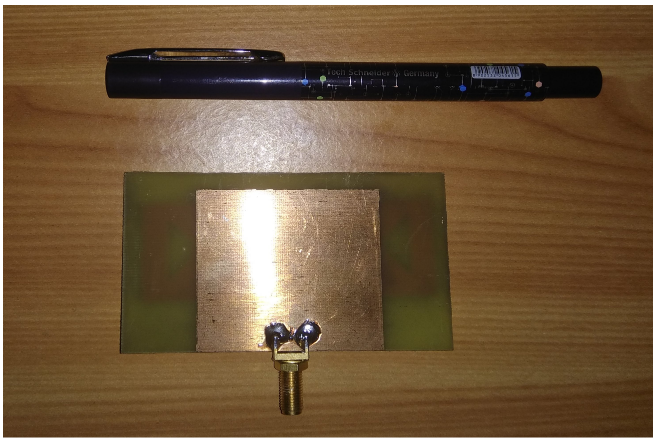

Figure 17 The Fabricated prototype of the proposed antenna; back view

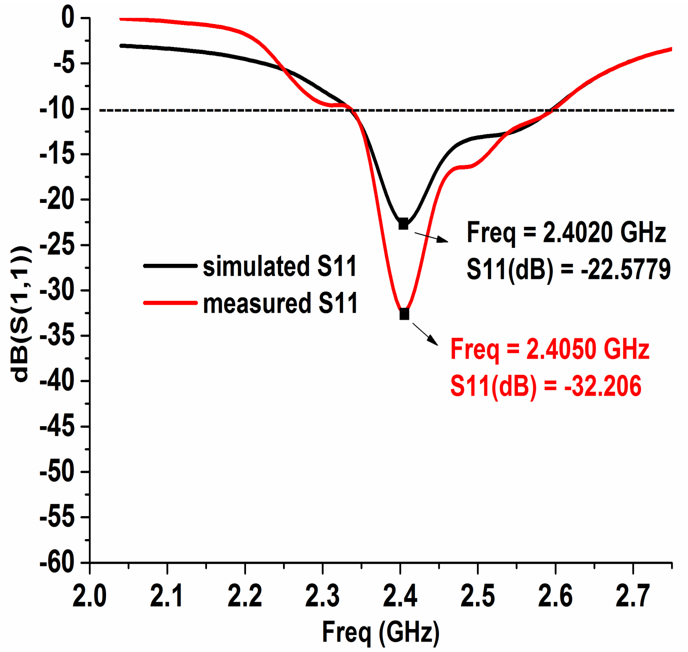

Figure 18 The S11 plot for the fabricated prototype

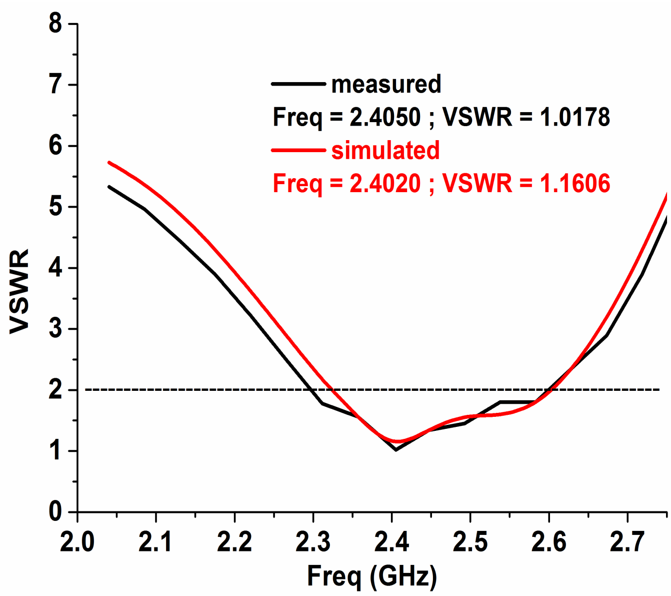

Figure 19 The VSWR plot for the fabricated prototype

The simulated S11 was calculated to be -22.5779 dB in the band range of 2.3 GHz to 2.6 GHz with the centre frequency 2.4020 GHz. The measured S11 was found out to be -32.206 dB in the band range of 2.3 GHz to 2.6 GHz with the centre frequency 2.4050 GHz. The Simulated VSWR was calculated to be 1.1606 (less than 2) and the measured VSWR was found out to be 1.0178 (less than 2). Therefore, the fabricated prototype is successfully tested and the measured results exhibited good agreement with the simulated results.

6. Conclusion

For the conventional 2 X 1 antenna array the gain was of "3.8 dB" and bandwidth was very low of "0.0757 GHz". To improve the gain of the given antenna array, dual trapezoidal slots were introduced into the patch. This made a significant improvement in the gain. The gain achieved was around "7.83 dB", and improvement is seen in bandwidth with "0.1244" GHz. Therefore, to further enhance the bandwidth of the antenna array, partial ground is considered. This further more improved the bandwidth and fractional decrease in the gain is seen. The dual trapezoidal slot antenna array with partial ground exhibited a gain of "7.0875 dB" bandwidth of "0.300 GHz".

It is to be noted that the trapezoidal slots made significant increase in the gain of the microstrip antenna array and on the other hand the partial ground structure improved the bandwidth of the microstrip antenna array while preserving the gain to the maximum possible extent. Therefore, the dual trapezoidal slot microstrip antenna array with partial ground structure is found to be work in the range of 2.3 GHz to 2.6 GHz with good bandwidth and gain. This frequency of operation covers the WiMax application with ranges (2.3 GHz to 2.4 GHz) and (2.496 GHz to 2.690 GHz).

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