Bandwidth Optimization of Microstrip Antenna for WiMAX Applications

T.Bonchak, A.T Adediji, P.Guyah

Abstract— This paper presents an optimized inset-fed rectangular microstrip patch antenna for WIMAX (3.5 GHz) applications. The bandwidth (BW) of a microstrip patch antenna is narrow which limits its operation in wireless communication. The bandwidth can be improved by symmetrically cutting a double I-shaped slot of size 2 mm x 10 mm from the patch, and U-shaped slot of size 2 mm x 22 mm from the ground with reference to the edges of the patch. The antennas were fabricated using FR4 board as substrate. Two types of antenna were fabricated, tested and characteristics compared, a conventional inset-fed microstrip patch antenna and, an optimized design of the inset-fed microstrip patch antenna. Different results were obtained depending on the parameters and measurement. The High Frequency Simulation Software (HFSS) solver was used to simulate the design. The two designs were compared to each other and found that some improvements were obtained on the optimized design. The bandwidth was improved from 54.1.5 MHz to 210 MHz.

Index Terms— U-Shaped Slot, I-Shaped Slot, WiMAX, Bandwidth Optimization, inset-fed, rectangular patch antenna, Truncated ground, HFSS,

1.INTRODUCTION

Worldwide interoperability for microwave access (WiMAX) is the implementation of the IEEE 802.16 family of wireless-networks standards ratified by the WIMAX Forum. Similarly, Wi-Fi is the implementation of the IEEE 802.11. WiMAX Forum certification allows vendors to sell fixed or mobile products as WiMAX certified, thus ensuring a level of interoperability with other certified products, as long as they fit the same profile. Wireless LAN standards are certified by the Wi-Fi Alliance. WIMAX can be used for a number of applications including providing portable mobile broadband connectivity across cities and countries through various devices, providing a wireless alternative to cable broadband connections, smart grids and metering, cellular backhaul, providing data, telecommunications (VoIP) and IPTV services etc. It is similar to Wi-Fi, but it can enable usage at much greater distances [1].

Since microstrip antennas have a narrow bandwidth, low gain and poor radiation efficiency. Surface waves pass through the substrate and are scattered at bends of the radiating patch which causes degradation of antenna performance [2]. To overcome this problem, the technique of using slots in the patch and truncating the ground structure are used. In this, way the surface wave is not excited easily and hence an improved bandwidth. Microstrip antennas designed for WiMAX usage have an inherent drawback of narrow bandwidth with a S_{11}< -10 dB bandwidth of only few percent. Therefore, design of microstrip antennas with a bandwidth higher than 100% is a challenging task for antenna designers. Numerous performance improvements have been used by the antenna research community to increase the bandwidth of microstrip antennas. Use of truncated or defected ground plates [3][4], etching slots or slits on the patch radiator [5][7], stacking multiple patch elements [8][9], use of non-conventional shapes for the patch [10][11] and inserting shorting pins connecting the, patch to the ground [12][13] are some of the widely used bandwidth enhancement techniques. These performance improvement techniques create several current paths with different lengths making the antenna resonates at multiple frequencies [14].

This paper proposes design of a microstrip inset-fed antenna by cutting an I-Shaped slot symmetrically on the patch radiator and a U-shaped slot on the ground to optimize the bandwidth. Section I is the introduction, section II describes the theoretical and design considerations. Section III presents the optimization process of antenna parameters, while section IV presents a discussion on the results. Finally, Section V concludes the findings.

11.THEORY AND DESIGN METHODOLOGY

To design the rectangular patch antenna, the following parameters has to be determine:

$\mathcal{E}_{reff}$= Effective dielectric constant
$\mathcal{E}_r$= Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch
L = Length of the patch

Assume Fig (1), a rectangular microstrip antenna of width W, length L resting on the height of a substrate h. The coordinate axis was selected as the height along z direction, length along x direction and width along y direction.

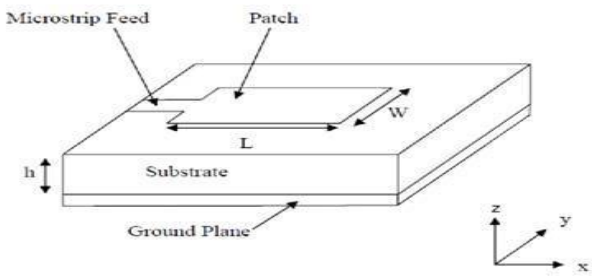

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Figure 1: microstrip antenna

The design calculation will be as follows:

a) Frings factor

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left[1 + \frac{h}{W}\right]^{-\frac{1}{2}} \ldots\ldots (1)$$

b) Calculation of length:

$$L = L_{eff} + 2\Delta L \ldots\ldots (2)$$

$$where \quad L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_r}}$$

c) Calculation of width:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \ldots\ldots (3)$$

d) Calculation of height of dielectric substrate (H):

$$H = \frac{0.3C}{2\pi f\sqrt{\varepsilon_r}} \ldots\ldots (4)$$

e) Calculation of the ground plane dimensions (Lg and Wg)

The transmission line model is usable to infinite ground planes always [15]. Therefore, for practical purpose, it is important to have a finite ground plane. It has been shown that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness around the periphery. For this design the ground plane dimensions are:

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

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

A 50Ω microstrip line with a width of 2.84 mm and length of 19.76 mm has been used to feed the radiating patch element (Fig. 1). Width of the microstrip feeding line *W* has also been calculated by using the standard equation (7).

$$Z_c = \begin{cases} \frac{60}{\sqrt{\varepsilon_{reff}}} ln\left[\frac{8h}{w} + \frac{w}{4h}\right] \frac{w}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{w}{h} + 1.393 + \frac{2}{3} ln\left[\frac{w}{h} + 1.444\right]\right]} \frac{w}{h} > 1 \end{cases} \ldots\ldots (7)$$

where Zc is the characteristic impedance.

Dimensions of the Antenna is shown on table 1. The patch size was designed in order to make the antenna resonate in the fundamental mode.

Table 1: Dimension of patch antenna

Parameters	Length (mm)	Width (mm)
Patch	20.22	26.33
Substrate	40.44	52.66
Ground	40.44	52.66
Feed	19.76	2.84
Inset gap	6.714	1.42

III. ANTENNA OPTIMISATION PROCESS

a) Software tool

The software used to model and simulate the microstrip patch antenna is ANSY HFSS. HFSS is a high-performance full-wave Electromagnetic(EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency, and Fields [15].

b) Structure of patch antenna design in HFSS

We have designed an array of rectangular patch antenna of the center frequency 3.5 GHz, sweeping between 2.15-5.4 GHz as shown on figure 2. Gain required as 6.7 dBi. We have employed an FR4_epoxy substrate with relative permittivity and thickness of 1.6 mm to design the two antennas.

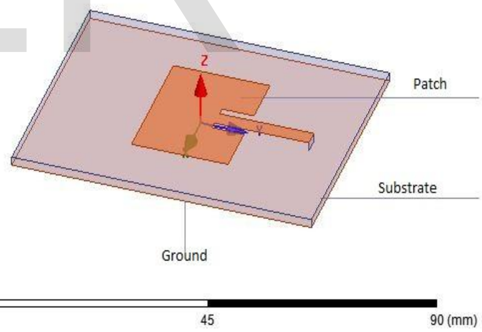

Figure 2: Antenna design in HFSS without optimization

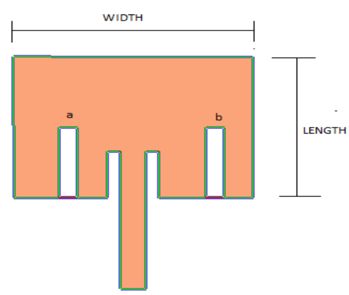

Figure 3: Double I-shaped slot on patch

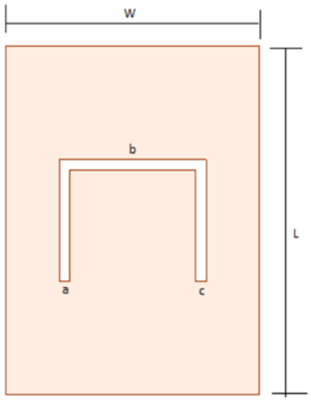

Figure 4: U-Shaped slot on ground in HFSS

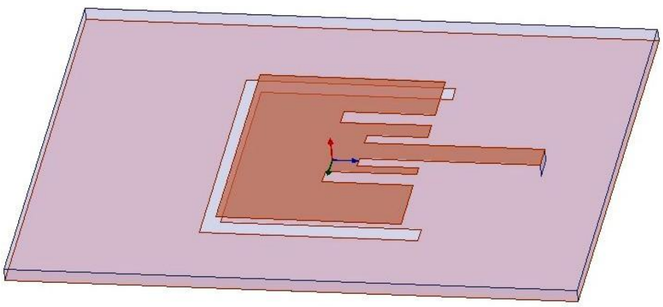
Figure 5: Final optimized antenna in HFSS

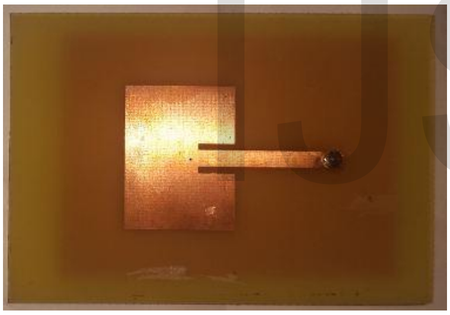
Figure 6a: Fabricated antenna without optimisation

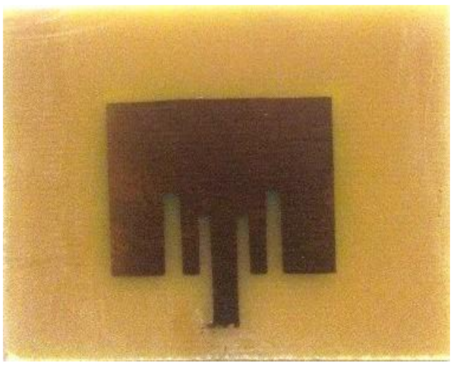
Figure 6b: Fabricated optimized antenna

c) Optimization of antenna

The optimization of the antenna involved two processes:

1. A slot of size 2 mm x 10 mm is placed on the patch at different positions. The return loss of the slotted patch antenna was compared with a conventional inset-fed antenna with no slot. The bandwidth varied in each case depending on the position of the slot. The maximum bandwidth was obtained, when the slot is placed near the transmission line. A second slot of the same size was also randomly placed on the patch, with the first slot on the patch. The bandwidth was maximum as shown on figure 3, when the slots are symmetrically place along the transmission line , this however reduced the return loss compared to the antenna with no slot.
2. Three (3) slots with uniform size 2 mm x 22 mm each are combined to form a U-shaped slot. The U-shaped slot was randomly placed on the ground plane of the antenna. The best return loss is obtained when the slot is symmetrically centered on the ground as shown on figure 4.

The two optimization processes are combined as shown in figure 5. The fabricated antenna without optimization as shown on figure 6a differed in performance compared to the fabricated optimized antenna on figure 6b.

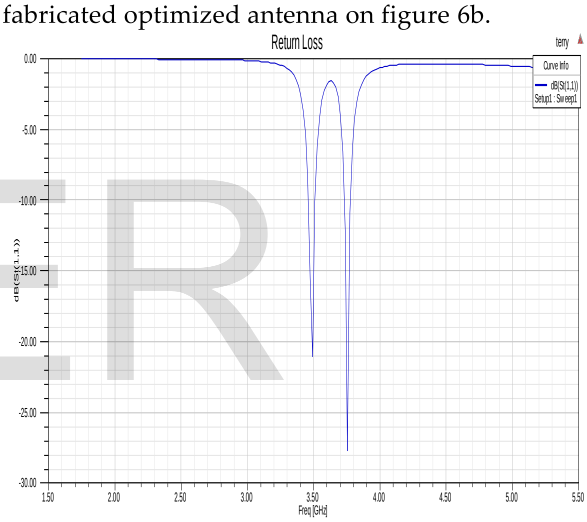

Figure 7: Return loss plot of double I-shaped slot on patch.

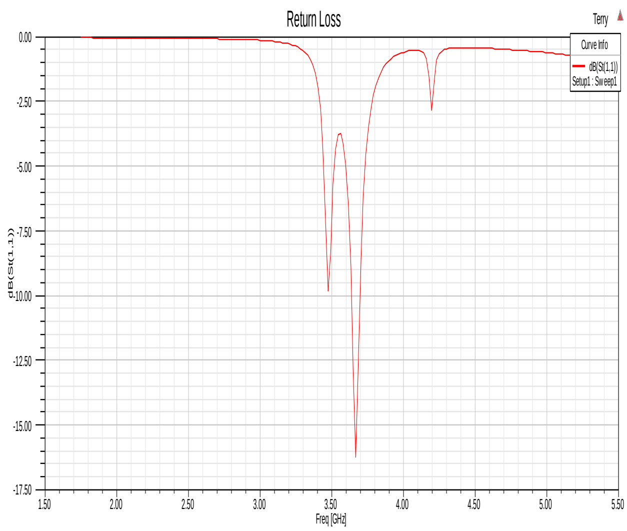

Figure 8: Return loss plot of U-shaped slot on ground plane

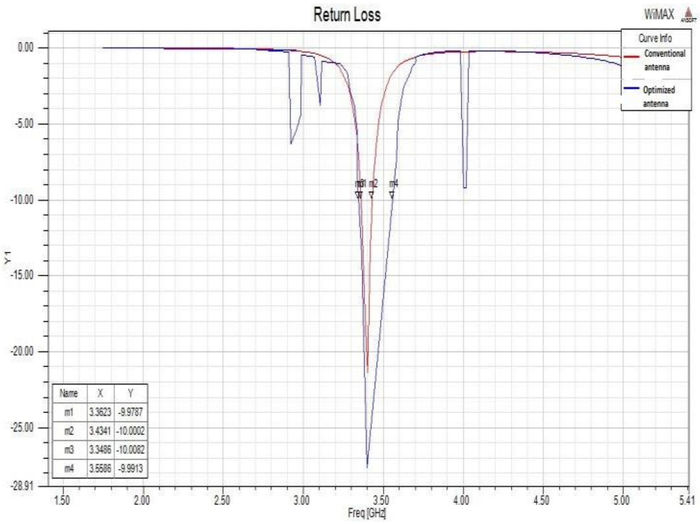

Figure 7: Return loss plot showing the improvement in bandwidth

Table 2: Comparison of measured return loss and bandwidth.

Radiation characteristics	**Conventional Microstrip antenna**	**Optimized microstrip design**
Return loss	-16.00 dB	-27.8 dB
Bandwidth	54.1 MHz	210 MHz

IV. DISCUSSION OF RESULTS

A double I- shaped slot only on the patch as shown on figure 7 resonates at dual frequencies of 3.5 GHz and 3.75 GHz in the S_{11}< -10 dB range. When a U-shaped slot only is truncated from the ground it produces the return loss plot as shown on figure 8. The combination of the two method of optimization yields the return plot chart on figure 9.

The conventional antenna as shown in figure 9 has a narrow bandwidth of 54.1 MHz and resonates at 3.5 GHz frequency. To optimize the antenna, three antenna parameters; position of the slot, length of the slot and width of the slot have been utilized.

The best bandwidth is obtained when the position of the slot is away from the edges but close to the transmission line. The Length and width of the slot also affects the antenna. A large slot size will mean a smaller patch size and hence an antenna with narrow bandwidth The bandwidth after optimization at S_{11}< -10 dB is from 3.37 GHz to 3.55 GHz. The initial conventional antenna without optimization had frequency range from 3.45 GHz to 3.51 GHz. Placing a slot on the ground plane makes the antenna to resonate at multiple frequencies, the resonance depends on the size of the slot and its position. When the antenna is optimized, it operates as an ultra-wideband antenna resonating at 2.91 GHz, 3.1 GHz, 3.5 GHz, and 4.08 GHz. They however resonate at S_{11}> -10 dB.

The increase from 54.1 MHz to 210 MHz for the same antenna as shown on table 2, is considerably a great improvement. This improvement has however increased the return loss, gain and directivity of the antenna. The antenna can operate over a wide range of frequencies but at a lower efficiency.

V. CONCLUSION

This paper presents bandwidth optimization of microstrip antenna at WiMAX frequency (3.5 GHz). The position of the slot, the width of the slot, length of the slot and the position of the slot on the ground plane are the factors that optimizes the bandwidth of the antenna. The U- shaped slot on ground plane optimizes the bandwidth the most, and also makes the antenna to operate at multi-band frequency.

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