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Gain and Bandwidth Enhancement of Rectangular Patch Antenna with Trapezoidal Slot for Wi-Max Applications

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***Abstract*- This paper presents the radiation performance of a rectangular patch antenna having a trapezoidal slot at the center of the glass epoxy FR4 substrate and its performance is compared with a conventional rectangular patch antenna. The simulated results for this antenna are obtained by varying the slot are studied. The results indicate that rectangular patch antenna with trapezoidal slot offers a much higher bandwidth (13.15%) in comparison to the conventional rectangular patch antenna (4.2%). Results also show that the gain of the modified antenna is improved w.r.t. the conventional antenna i.e., the gain becomes 3.30 dBi from 1.94 dBi just by varying the dimensions of slot. The resonant frequency lies in the higher band (5.25 to 5.85 GHz) allotted by IEEE 802.16 working group for Wi-MAX systems. The performance of the antenna is optimized considering different slot variance to obtain an antenna with high bandwidth performance. The radiation pattern, gain and radiation efficiency of an antenna are also determined.**

I. INTRODUCTION

Microstrip antennas have many advantages over the conventional antennas such as low profile, ease of integration with active and passive devices, ability of mounting on planar, non-planar and rigid exteriors to form MICs and low manufacturing cost due to use of printed circuit technology. In case of planar antennas designed for wireless communication systems, it is necessary to have a compact size antenna configuration that can be integrated with other devices. Since the physical area of the microstrip antenna is inversely proportional to the frequency, it is difficult to achieve a compact size antenna for modern communication systems for WLAN, WiMAX and Wi-Fi applications, particularly with normal patch geometries having acceptable efficiency and isolation values. There is often a trade off in realizing compact antennas while maintaining their performance characteristics. Traditional patch antenna using rectangular, circular or triangular geometries under normal conditions resonate at a single frequency and have the inherent low bandwidth and gain values limiting their potential applications. Present day communication systems need dual or triple frequency operation with higher bandwidth. Microstrip antennas for dual frequency applications have been realized by exciting patch geometry by using a single or dual feed arrangement. In the present work, we have considered a more simplified antenna structure by applying the trapezoidal patch in the center of a rectangular patch antenna and changed the size of the slot to optimize and attain the best performance.

II. METHODS

A. Method of Moments (MoM)

Analysis of various MSAs done by IE3D software is based on MoM. In the MoM, the surface currents are used to model the microstrip patch, and volume polarization currents in the dielectric slab are used to model the fields in the dielectric slab. An integral equation is formulated for the unknown currents on the microstrip patches and the feed lines and their images in the ground plane. The integral equations are then transformed into algebraic equations that can be easily solved using a computer. This method takes into account the fringing fields outside the physical boundary of the two-dimensional patch, thus providing a more exact solution.

B. Coaxial Probe Feed Technique

The inner conductor of the SMA connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

III. ANALYSIS AND MODELING

It is useful to model the microstrip antenna as a transmission line. This model is the simplest of all and it gives good physical insight, but it is less accurate.
In this model the MSA can be represented by two slots of width (w) and height (h) separated by transmission line of length (L). The width of the patch can be calculatedfrom the following equation [7].

$$W = \frac{C}{2 f_o \sqrt{(\varepsilon_r+1)/2}} \text{.....................................(1)}$$

The effective dielectric constant (ε_{eff}) is less than (ε_r) because the fringing field around the periphery of the patch is not confined to the dielectric speared in the air also.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{\frac{1}{\left[1+12\frac{h}{w}\right]}} \text{.................(2)}$$

In order to operate in the fundamental TM10 mode, the length of the patch must be slightly less than λ/2 where λ is the wavelength in the dielectric medium.

The difference in the length (ΔL) which is given empirically by is given below.

$$\Delta L = 0.412h \frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.813\right)} \text{..........(3)}$$

$$L_{eff} = \frac{C}{2 f_r \sqrt{\varepsilon_{eff}}} \text{....................................(4)}$$

Where c=speed of light, L_{eff}= effective length, f_r =Resonance frequency, ε_{eff}= effective dielectric constant.

IV. DESIGN CONSIDERATION

A. *Substrate selection*

The first step in the design is to choose a suitable dielectric substrate of appropriate thickness (h) and loss tangent. A thicker substrate, besides being mechanically strong it will increase the radiated power, reduce the conductor loss and improve impedance bandwidth.

B. *Width and length parameters*

A larger patch width increases the power radiated and thus gives decreased resonant resistance, increased BW and increased radiation efficiency. With properexcitation one may choose a patch width (W) greater than patch length. It has been suggested that 1< W/L< 2. In case of microstrip antenna, it is proportional to its quality factor Q and given by as:

$$BW = \frac{\mathrm{VSWR}-1}{Q\sqrt{\mathrm{VSWR}}} \text{..(6)}$$

The percentage bandwidth of the rectangular patch microstrip antenna in terms of patch dimensions and substrate parameters is given as follows:

$$BW\,\% = \frac{Ah}{\lambda_o}\sqrt{\frac{W}{L}} \text{..........................(7)}$$

Where:

A =180 for $\frac{h}{\lambda_o\sqrt{\varepsilon_r}} \leq 0.045$

A =200 for $0.045 \leq \frac{h}{\lambda_o\sqrt{\varepsilon_r}} \leq 0.075$

A =220 for $\frac{h}{\lambda_o\sqrt{\varepsilon_r}} \geq 0.075$

Where
h = substrate thickness
λ= wavelength in the substrate
ε_r= dielectric constant of the substrate
w = width of patch dimension
L = length of patch dimension

V. DESIGN PARAMETERS

The dielectric material selected for this design is FR4 substrate which has a dielectric constant of (ε_r =4.4), loss tangent (tanδ) = 0.025, the height of the dielectric substrate is (h = 1.6) mm. The resonant frequency of the antenna must be selected properly. The Wi-MAX applications use the frequency range from (5.25-5.85) GHZ. Resonant frequency selected for this design is 5.31 GHZ. It includes calculation of width (w), effective dielectric constant, length extension, effective length, actual length of patch (L), ground plane dimensions (L_g and W_g), feed point location (x_f, y_f).

Y_f = w/2.....................

$X_f = L / (2\sqrt{\varepsilon_{eff}}\,)$..................(8)

VI. BANDWIDTH ENHANCEMENT TECHNIQUE

Larger bandwidth can be achieved by loading slots within the patch of the antenna and with different shapes, arrangements and sizes the effect of this techniques on increasing the bandwidth is more than using the other techniques such as higher dielectric constant substrate, a slot cut inside the patch for broader BW, thicker and lower dielectric constant substrates and single slot cut. A single trapezoidal slot cut in probe feed rectangular patch with dimensions [L=40mm; W=25mm] operating at resonance frequency 5.31 GHz. The patch is excited by (50) ohm, coaxial cable at feed position (which gives the best matching result in this work.) A dielectric substrate of (ε_r= 4.3), with loss tangent = 0.025 has been used, the substrate thickness (h) = 1.6 mm. Single trapezoidal slot with different dimensions and locations were tested in this work. The performance (BW, radiation patterns) was studied and analyzed for the simulated configurations.

VII. SIMULATION RESULTS

In the present paper, radiation performance of a rectangular patch antenna with trapezoidal slot at the centre is considered and is compared with that of a conventional rectangular patch antenna. The antennas are simulated using IE3D EM simulation software. The patch size of 4cm x 2.5cm is considered for the present work. At the beginning of designing process, first we considered a single layer conventional microstrip patch antenna. FR4 substrate was used to design this conventional patch. The Z top for FR4 substrate is 1.6mm and loss tangent for FR4 is 0.025 and Dielectric constant is 4.4. Simple probe feed technique was used for excitation. Design and simulation process were carried out using IE3D simulation software version 12.30. Fig. 1 shows the conventional patch.

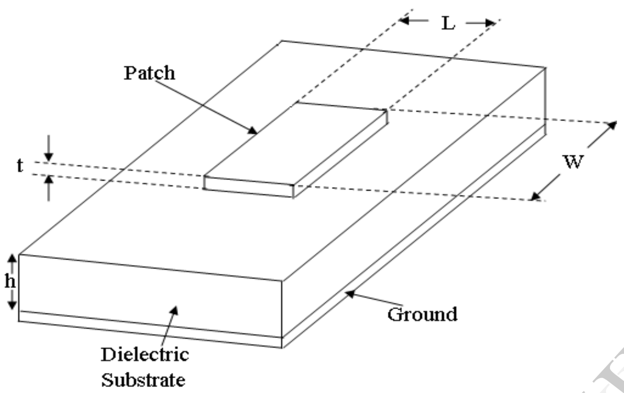

Fig 1: Rectangular Patch (40mm x 25mm**)**

Simulated reflection coefficient curve for conventional patch is shown in fig. 2. From this curve we saw that conventional patch is resonant at 5.3 GHz with bandwidths of 4.2%.

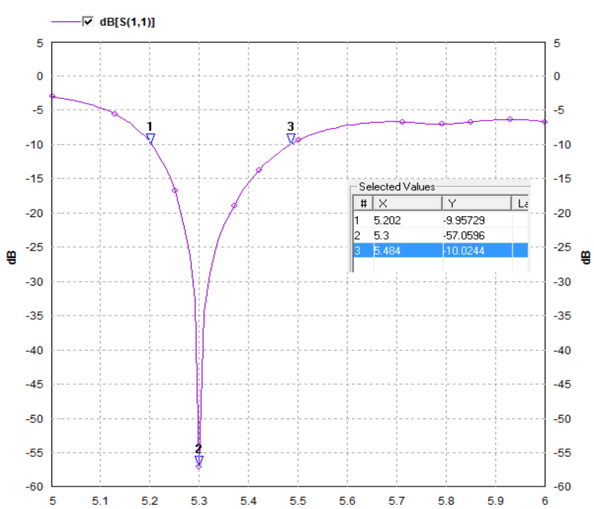

Fig 2: Simulated return loss of rectangular patch antenna

Since conventional patch has low bandwidth, further modifications are required. Smith chart for conventional patch is shown in fig. 3.

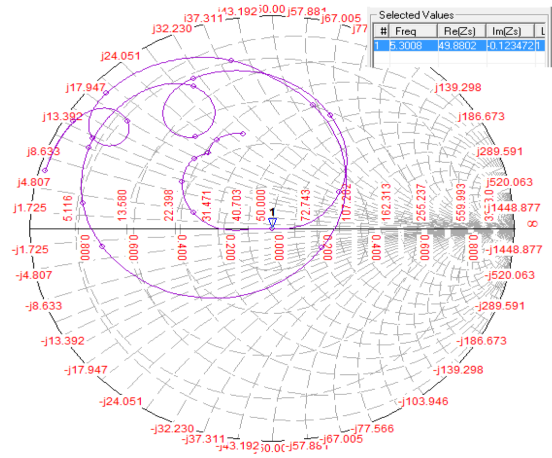

Fig 3: Comparison of impedance with frequency

In our next step of designing process we modified our conventional patch to get enhance bandwidth. In modified patch, one trapezoidal slot were inserted into conventional patch. Dimensions of modified patch were remained same as in conventional patch. Dimension of slits are shown in figure4. All basic parameters for modified patch were same as in conventional patch because we used FR4 substrate again. Fig. 4 represent modified single layer microstrip patch antenna.

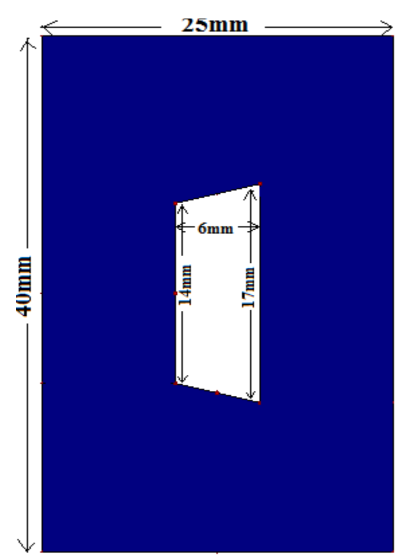

Fig 4: Rectangular patch with trapezoidal slot

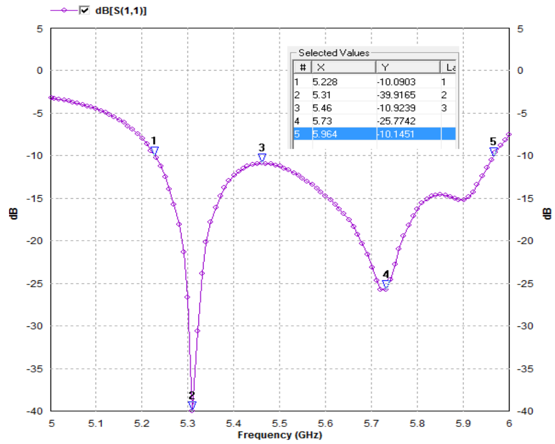

Fig 5: Simulated return loss of rectangular patch with trapezoidal slot.

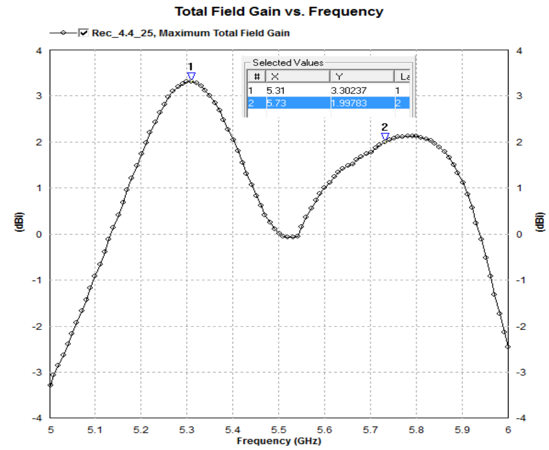

Fig 8: Total field gain vs frequency graph

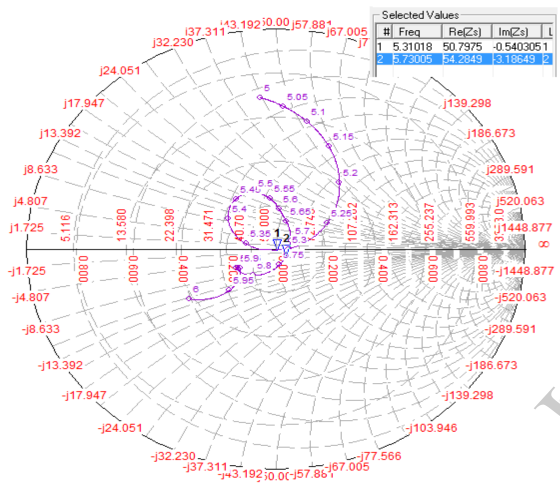

Fig 6: Comparison of impedance with frequency for trapezoidal slot.

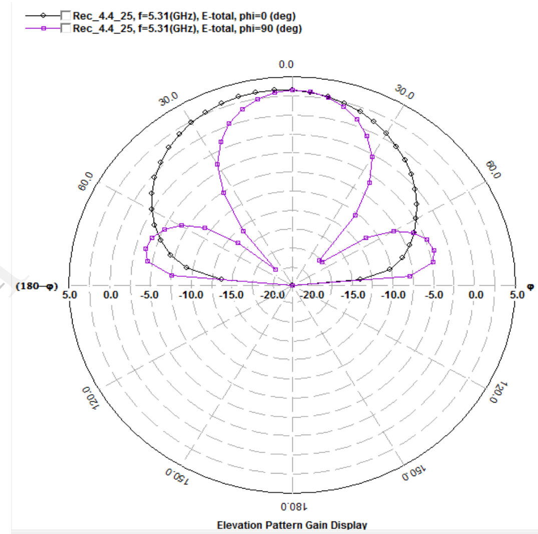

Fig 9: Elevation pattern gain display

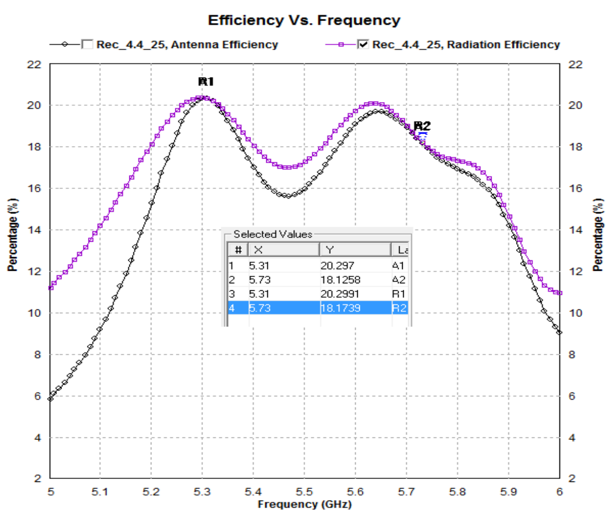

Fig 7: Efficiency vs frequency graph

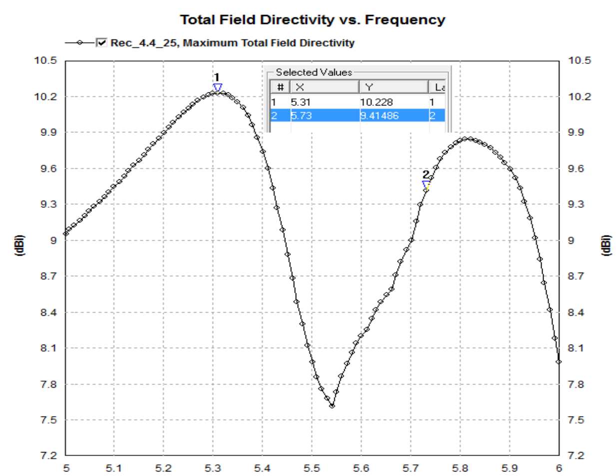

Fig 10: Total field directivity vs frequency

VIII. CONCLUSION

Radiation performance of a trapezoidal slotted rectangular patch antenna is presented in this paper. The simulated results indicate that an antenna with a higher bandwidth may be achieved by cutting a trapezoidal slot in the center of the rectangular patch antenna. In this work the bandwidth of antenna is optimized by varying the slot dimensions. An optimum bandwidth (13.15%) is achieved at a resonant frequency of 5.31GHz. The resonant frequency lies in the higher band (5.25 to 5.85 GHz) allotted by IEEE 802.16 working group for Wi-MAX systems. The gain of antenna is also improved (3.30 dBi) and maximum radiations are normal to the patch antenna geometry. Further work on antennas is being carried out to enhance the performance further.

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TABLE 1

Comparison of Conventional Antenna and Modified Antenna with Trapezoidal Slot.

Antenna Geometries	**Feed Location (mm)**	**Resonant Frequency (GHz)**	**Return Loss (dB)**	**Gain (dBi)**	**Band Width (%)**
Rectangular MSA	x=2.30 y=2.75	5.3	-55.4	1.94	4.2
RMSA with Trapezoidal slot	x=9.50 y=10.18	5.31	-39.9	3.30	13.15