Bandwidth Enhancement of a Compact Microstrip Patch Antenna for Different Wireless Applications.

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Abstract- **The performance and advantages of microstrip patch antennas such as low weight, low profile, and low cost made them the perfect choice for communication engineers. Current technological trend has focused much more attention towards microstrip patch antennas, but it has little drawbacks like low gain, low efficiency, low directivity and narrow bandwidth (3-6%) of the central frequency. Its bandwidth is limited to a few percentage which is not enough for most of the wireless communication systems nowadays. One of the challenges in antenna design for modern wireless communication system is to construct a single antenna that can serve a non-contagious frequency allocation using various wireless technologies. In this paper, a wideband antenna design approach is proposed to produce a single antenna that can be used by various wireless technologies using different frequencies from 2 to 8.2 GHz, covering 2.1 GHz for 4G-LTE, WiFi frequencies at 2.4-2.5 GHz, 5-5.35 GHz and 5,7-5,8 GHz, as well as WiMax frequencies at 2.3-2.4 GHz, 2.4-2.6 GHz, 3.3-3.8 GHz, and 5.25 5.85 GHz. The antenna construction consists of a truncated patch with a coplanar waveguide (CPW)-fed line, printed on an 1.6 mm thick of FR4 dielectric substrate with permittivity εr=4.4. The simulation results of proposed antenna are based on the reflection coefficient and radiation pattern. A fractional bandwidth of 196.6% from 1.6 to 7.5 GHz and Omni-directional radiation pattern. The simulation of this antenna has been performed by using Ansoft HFSS.**

Keywords - **Voltage Standing Wave Ratio (VSWR), Return Loss (S), Coplanar Waveguide (CPW).**

I. INTRODUCTION

Due to the rapid development in the field of wireless communications, there is an increasing demand for higher data rate and large bandwidth. A Microstrip Antenna in its simplest form consists of a radiating patch on one side of dielectric substrate and ground plane on other side. Microstrip Patch Antennas are popular for their well-known attractive features, such as a low profile, light weight, and compatibility with Monolithic Microwave Integrated Circuits. Modern Communication Systems, such as those for satellite links (GPS, Vehicular, etc.), as well as emerging applications, such as Wireless Local Networks (WLAN), require antennas with compactness and low-cost, thus rendering planar technology useful, and sometimes unavoidable. Conventional microstrip patch antennas have some drawbacks of low efficiency and narrow bandwidth [1,2] of the central frequency. its bandwidth is limited to a few percentage which is not enough for most of the wireless communication systems [1]. Several designs have been investigated and reported to decrease the size of antenna and to improve the bandwidth of antenna[1]. The capacity of a communication channel in a non-fading environment is expressed as:

$$C = B * \log_2 (1+S/N) \quad (1)$$

where
C = channel capacity (bit/s) .
B = channel bandwidth 'BW' (Hz) .
S = signal power (watts) .
N = noise power (watts) .

According to the above equation, the capacity can be increased by either increasing B or S/N. It is obvious that the capacity can be increased more by increasing B rather than S/N. Wideband antenna systems could also suffer from interference from other wireless technologies that exist in the vicinity of operation, but this problem can be mitigated by using adaptive selection of frequency bands in multi band systems. Recently, microstrip antennas have been one of the most innovative topics in antenna theory and design and are increasingly finding application in a wide range of modern microwave systems [3]. This paper presents an overview of the basic characteristics of microstrip antennas and the development in microstrip antenna technology. In addition, a new antenna configuration for improved bandwidth is also discussed.

II. A. PROBLEM STATEMENT

The main limitation of microstrip patch antenna is the lower bandwidth, which effects wireless communication applications. Bandwidth of microstrip antenna can be improved by increasing the height of substrate by using the transmission line model. At the same time, increasing height of the substrate also increases the surface waves, which move from end to end around the substrate and spread at the curves of the radiating patch, which adopts apart of energy of the signal. thus, declining the antenna's performance. In order to avoid this problem, different techniques are used such as air gap technique in which surface waves are not produced. Further, length of patch plays an important role in bandwidth of antenna. Antennas having minimum possible size are considered efficient.

III. TECHNIQUES OF BANDWIDTH ENHANCEMENT

Microstrip antenna in its regular shape cannot yield multi-octave BW because of its resonant nature. Some

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modification of the microstrip antennas configuration is required to obtain an octave BW. If a rectangular patch without the substrate and ground plane is fed at the edge by a coaxial feed with a perpendicular ground plane, then the patch will have an effective dielectric constant equal to 1 with large h. Both of these factors yield broad BW. This modified configuration can be thought of as a planar rectangular monopole antenna. Other configurations such as triangular, hexagonal, circular, and elliptical monopoles also yield broad BW [4]. An elliptical monopole with an elasticity of 1.1 yields BW of 1:11 for VSWR < 2 .

The BW could be defined in terms of its VSWR or input impedance variation with frequency or in terms of radiation parameters. For the circularly polarized antenna, BW is defined in terms of the axial ratio (AR).Therefore, before describing the various methods for increasing the BW, the various definitions of the BW are described. The VSWR or impedance BW of the microstrip antennas is defined as the frequency range over which it is matched with that of the feed line within specified limits. The BW of the MSA is inversely proportional to its quality factor Q and is given by [4].

$$\mathrm{BW} = \frac{\mathrm{VSWR}-1}{Q\sqrt{\mathrm{VSWR}}} \qquad (2)$$

The BW is usually specified as frequency range over which VSWR is less than 2 (which corresponds to a return loss of 9.5 dB or 11% reflected power). Sometimes for stringent applications, the VSWR requirement is specified to be less than 1.5 (which corresponds to a return loss of 14 dB or 4% reflected power). Conversion of BW from one VSWR level to another can be accomplished by.

$$\frac{\mathrm{BW1}}{\mathrm{BW2}} = \frac{(\mathrm{VSWR}_1-1)\sqrt{\mathrm{VSWR}_2}}{\sqrt{\mathrm{VSWR}_1}(\mathrm{VSWR}_2-1)} \qquad (3)$$

where BW1 and BW2 correspond to VSWR1 and VSWR2, respectively. The expressions for approximately calculating the percentage BW of the microstrip antennas in terms of patch dimensions and substrate parameters is given by.

$$\%\mathrm{BW} = \frac{Ah}{\lambda_0\sqrt{\varepsilon_0}}\sqrt{\frac{W}{L}} \qquad (4)$$

Where, W and L are the width and length of the microstrip patch. With an increase in W, BW increases.

IV. Microstrip Antenna Analysis

The rectangular microstrip patch is probably the most common designed antenna. The Fig. 1, shows a normal rectangular patch antenna. Here, a designer has two degrees of freedom length and width of patch.

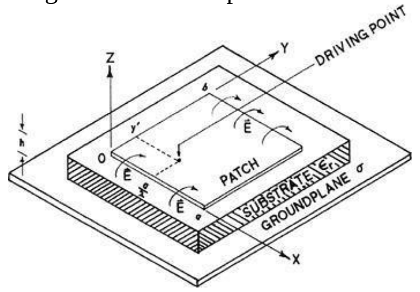

Fig. 1. Rectangular patch antenna.

The metallic patch is separated from the ground plane by a fraction of wavelength distance above by the dielectric substrate. The field varies over the length are shown in "Fig. 1". The fringing fields are coming out from the two edges are referred as radiating edges and other two edges as non radiating edges [5]. The patch shown in Fig. has length L and width W. The patch antenna is fed by a coaxial line feed and the feed point is on the middle line on the patch y' distance apart along the length b.

A- Methods of Analysis.

A number of methods are available for analyzing the microstrip antenna. Two of the mostly used models are named below. Transmission line model is the first and provides a simple physical implementation of the antenna but is less accurate, Whereas the cavity model is difficult, but more accurate.

The Performance of the microstrip antenna depends on its dimension. Depending on the dimension the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced. For an efficient radiation, the practical width of the patch can be written as [5].

$$W = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad (5)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (6)$$

Where

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (7)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right))}{(\varepsilon_{reff}+0.258)\left(\frac{W}{h}+0.8\right)} \qquad (8)$$

and the ground plane are:

$$W_g = 6.h + W \qquad (9)$$

$$L_g = 6.h + L \qquad (10)$$

where f_r is the resonant frequency, L and W are the length and width of the patch element respectively and ε_r is the dielectric constant.

Motivated the wide range of applications in the antenna world the interested people to do a lot of designs and modifications. The idea of this work is to design microstrip patch antenna for ultra-wideband, WiMax and 4G application. In this paper, the proposed antenna is designed using HFSS software. The dimensions are calculated theoretically as they mentioned in analysis microstrip antenna using transmission line method equations and using MATLAB in calculations.

V. Design Specifications of CONVENTIAL Microstrip Antenna (2.5 GHz)

A- Antenna design.

A one band microstrip patch antennas was designed using HFFS software. The antenna is designed to operate in 2.5 GHz. The antennas shape was chosen to be a square patch antenna with the dimension W×L and FR4 substrate with the dielectric constant of 4.4, and its height is equal to 1.6 mm. The feeding technique is microstrip

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transmission line, which is an easy technique to be calibrated and fabricated. The dimension of microstrip feed line for matching was calculated with microstrip calculation equations.

The antenna is shown in Fig. 2. After simulation and optimization using HFFS Software.

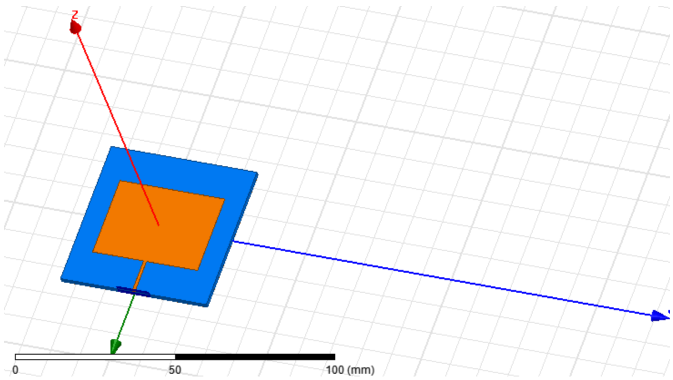

Fig. 2. Front view of 2.5 GHz -band microstrip antenna, dimensions in (mm).

Table 1. gives us the design parameter specifications of the 2.5 GHz microstrip antenna.

Table 1. Design parameter specifications of the 2.5 GHz microstrip antenna

Parameter	Value
Operating frequency	2.5 GHz
Dielectric Constant	FR (4.4)
Height of the substrate	1.6 mm
Width of the patch (W)	36 mm
length of the patch (L)	27 mm
Width of the ground (W_g)	70 mm
length of the ground (L_g)	55 mm
Z_0	50

The published structure is carried out in HFSS. The necessary simulations are carried out to obtain the scattering parameters.

B- Simulation results.

Antenna Return Loss (RL): The simulated reflection coefficient of the microstrip antenna is shown in "Fig. 3". It is obvious that the reported antenna operating band (under -10 dB) at centered 2.5 GHz -14.39 dB), with bandwidth which extends from 2.43 GHz to 2.54 GHz (BW=4.4 %). So, it is quite clear that this operating band meets the design requirements operating frequency.

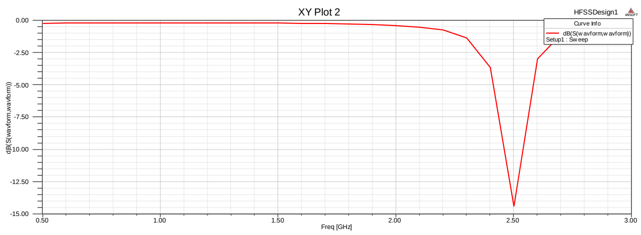

Fig. 3. Microstrip antenna return loss at 2.5 GHz.

Radiation Pattern: The radiation patterns for the design microstrip patch antenna are shown in Fig. 4. The antenna design has Omni-directional shaped radiation patterns in the phi=0 deg (x-y plane) and phi=90 deg (y-z plane) planes.

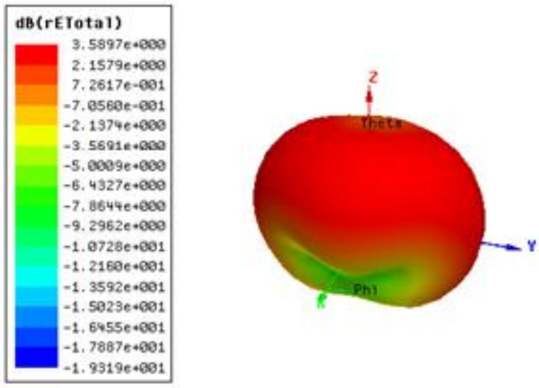

Fig. 4. 3D radiation pattern of the microstrip antenna.

One of the challenges in designing a design compact is low cost and wide bandwidth. The microstrip antenna is considered a good candidate for wireless applications because it is low profile, etched on a single substrate and can provide the feature of multi-band and wideband operation.

VI. PROPOSED MICROSTRIP ANTENNA WITH BANDWIDTH INCREMENT BY CUTTING EDGES

The bandwidth of operation of antenna depends upon different parameters like size of an antenna, thickness and dielectric constant of substrate material used, proper impedance matching of connector and antenna etc. Apart from these parameters, structure of the radiating patch and ground also plays an important role in deciding the bandwidth. Cutting corners of microstrip antenna will induce more discontinuity in the flow of wave and increasing reflections will ultimately result in improved bandwidth.

This section deals with the design of wideband antenna for substrate FR4, based on the resonant frequency and dielectric constant 4.4. Coplanar waveguide (CPW) is used for this UWB Antenna design. Coplanar waveguide (CPW) is formed from a conductor separated from a pair of ground planes, all on the same plane. The CPW fed antennas have wider bandwidth, better impedance matching and easy integration with active devices or monolithic microwave integrated circuits.

Keeping all parameters of design of simple microstrip antenna constant, design is modified by cutting the corners of rectangular patch by straight edges. As shown in Fig. 5 and Fig. 6, antenna is of dimension, i.e. same as single band antenna. Corners of the radiating patch are truncated with length 'CUT'. This cutting edge 2x1mm length with step size of 2 mm and simulated in software.

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Fig. 5. Structure of proposed microstrip antenna.

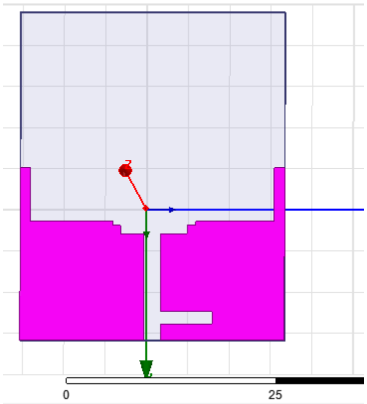

Fig. 6. Ground plate of proposed microstrip antenna.

The frequencies for the reason that of the footsteps at the lowermost part of rectangular patch, the rapid changes in the geometry of patch antennas indications to a cutout in the microstrip line [6]. Due to the technique, wider bandwidth is obtained, which produces capacitive coupling between the ground plane and patch of the antenna [6]. Magnetic and electric field spreading are altered nearby the discontinuity when the geometry of antenna ups and downs. Thus, the incoherence due to footsteps can be symbolized as corresponding circuit as three times of spilt LC circuit as shown in Fig. 7,.

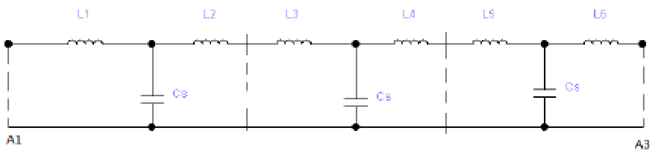

Fig. 7. Corresponding circuit of proposed antenna.

VII. A. SIMULATION RESULTS

Microstrip antenna with edge cut can be observed when the bandwidth of operation of antenna increases. Due to physical limitations of radiating patch dimensions, this truncation length can't be further increased. Fig. 8, shows the reflection coefficient of this antenna according to the frequency. This result shows the presence of a resonance frequency at 5.7 GHz with a level of S11 parameter at -32.57 dB. Bandwidth measured at -10 dB ranges from 1.6 to 7.5 GHz (196.6 % BW). The bandwidth increase of proposed antenna is obtained merely by changing the shape of radiating patch. Lower frequency end does not change very much but cutting corner edges effect on higher cut off frequency which goes on increasing exponentially.

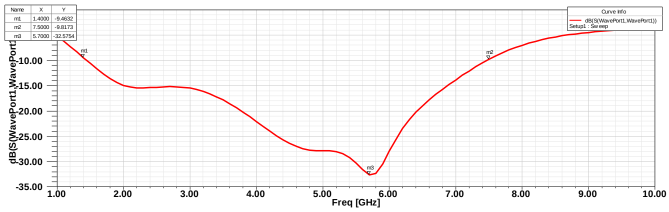

Fig. 8. Return Loss vs. Frequency for modified microstrip antenna with straight edge cut.

From Fig. 9, The VSWR is also minimum at the range of the specified frequency of operation. This means that good signals are received.

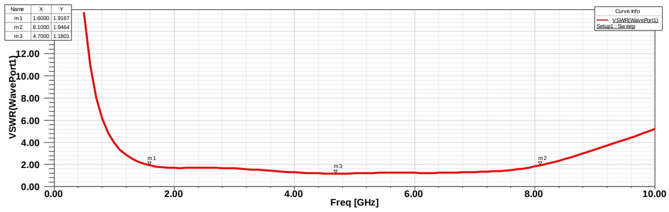

Fig. 9. VSWR vs. Frequency for proposed antenna.

Current distribution, Fig. 10, illustrates the current distribution of proposed antenna. It is clear from the Fig. that the amount of current declines at the start and edge of patch. The Figure shows the current distribution pattern at 5.7 GHz band, the red arrows show the strongest current distributed in the patch of antenna.

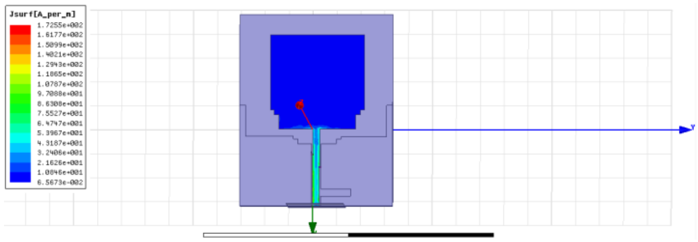

Fig. 10. Average current distribution of the proposed antenna.

Fig. 11, shows the radiation patterns of the proposed antenna at four frequencies of 2.1 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz. It is observed that at frequencies field patterns are approximately bidirectional and the antenna has a main beam in the broadside direction. As the frequency increases, higher order current modes are excited and the radiation patterns becomes slightly directional. However a stable and symmetric the radiation patterns are observed over the entire operating band of the proposed antenna which is similar to a typical monopole antenna.

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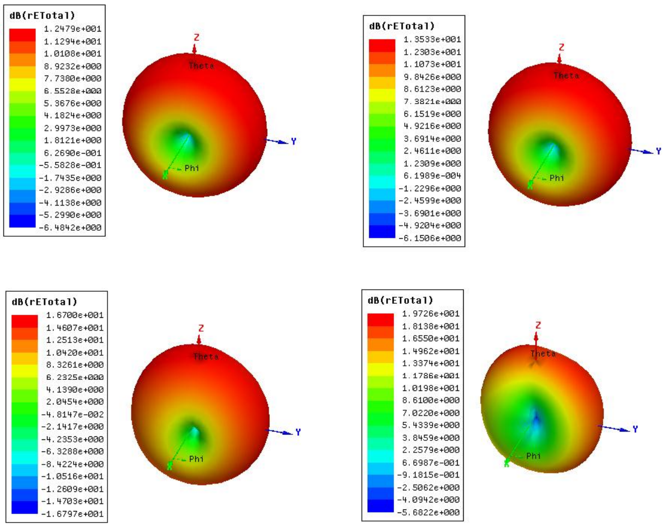

Fig..11. 3D Radiation pattern of the radiating patch at 2.1 GHz, 2.5 GHz, 3.5 GHz, 5.8 GHz.

IV. CONCLUSIONS

This paper presented the development of a simple, compact and ultra-wideband microstrip antenna. Simulation results demonstrated the potential of the proposed antenna based on the reflection coefficient, radiation pattern and gain. A fractional bandwidth of 196.6 % from 1.6 to 7.5 GHz and Omni-directional radiation pattern. We showed that by embedding a slots and edges with a proper dimension and position in the partial ground plane, a wide impedance bandwidth from 1.6 to 7.5 GHz (5.9 GHz) with VSWR<2 is achieved. Also reduction size antenna with 45% compared conventional microstrip antenna. In addition, the antenna is compact and can cover the whole frequency band of 2.1 - 2.5 - 3.5 - 5.8 GHz bands of 4G-LTE, WLAN, ITU, WiMAX communication systems and European standard UWB systems, it should be a promising candidate for such applications.

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