A 28-GHz U-slot Microstrip Patch Antenna for 5G Applications

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***Abstract*— In this study, a 28-GHz U-slot rectangular microstrip patch antenna for 5G Applications is proposed. The U-slot antenna concept has been used in patch antenna designed to reduce antenna size.The U-slot patch antenna structure consists of a patch, U-shaped slot, a ground plane and coaxial feed lines. The proposed antenna is designed and fabricated to meet the best possible result using a simulation software: Ansoft HFSS (High Frequency Structure Simulator) software version 15.0. Microstrip patch antennas are widely used because of their several advantages such as light weight, low volume, small size and low fabrication cost. The proposed antenna was measured and compared with the simulation results to prove the reliability of the design. The performance of the designed antenna was analyzed in term of gain, return loss, VSWR, and radiation pattern at frequency is 28 GHz.**

***Index Terms*— 28 GHz, 5G, U-slot Antenna, Microstrip Antenna, Coaxial Feeding, HFSS.**

I. Introduction

The development of a 5G system has been begun recently to obtain higher data rates. The standardization activity of 5G is expected to be available in the early 2020s. Compared with a 4G system, the 5G system uses millimeter-wave bands, which are a challenging requirement in the design of an antenna in 5G mobile systems. As the mobile industry looks toward scaling up into the millimeter-wave spectrum, carriers are likely to use the 28, 38, and 73 GHz bands that will become available for future technologies [1–3].

Microstrip antennas have become attractive for use in mobile applications. This antenna has attracted much interest because of its low profile (i.e., compact size), light weight, low cost mass production, and ease of installation. However a major limitation in its application is its narrow bandwidth. The technique that has been used extensively for increasing bandwidth is stacked patches, in which a parasitic element is placed vertically over the lower patch. A microwave antenna that introduces a U-slot or slit into a rectangular radiating patch is a simple and efficient method for obtaining the desired compactness and multiband and broadband properties, as this shape radiates electromagnetic energy efficiently. This design avoids the use of stacked or parasitic patches, and etching U-slot on the patch is simple [4–7].

It is derive that the resonant frequency is inversely proportional to the slot length and feed point and at the same time as it increases with increasing the coaxial probe feed radius and slot width [8]. In recent years, some papers were reported for Dual/triple band operation by using single/double U slot in the microstrip antenna. It is seen that the applications which require dual frequency operation with small frequency ratio were designed by using the U slot in a wideband micro strip antenna [9]. Micro strip antennas are suffer from low impedance bandwidth characteristics to increase 5G system applications. To avoid this suffering of antennas, there have been various bandwidth enhancement techniques like coplanar parasitic patches, stacked patches, or novel shapes patches such as the U and H -shaped patches. Here in this design one method is used, called as special feed networks or feeding techniques, to compensate for the natural impedance variation of the patch. To avoid the use of coplanar or stacked parasitic patches we can do the etching process on the patch with U -slot, which increases either the lateral size or the thickness of the antenna. So, sometimes with enhancing the impedance bandwidth, changing the current distribution on the micro strip patch more than one resonant frequency is obtained. In 1995, two scientists named as Huynh and Lee was presented a broad band single layer probe fed patch antenna with a U -shaped slot on the surface of the rectangular patch [10-13].

In this paper, we design a rectangular microstrip patch antenna in which U shaped slots are cut in microstrip patch to enhance its bandwidth and frequency response.

II. Antenna Design and Analysis

Microstrip antenna in rectangular shape is the easiest geometry for designing and implementation. The basic U -slot loaded rectangular micro strip patch antenna design is seen in below Figure. 1. Here, W is the patch length, L is the patch width, d is the feed point, Uy1 is the vertical slot length, Ux1 is the horizontal slot length, Ua1 is a slot thickness.

The proposed antenna is fabricated using Roger RO 4350(tm) substrate with thickness of 1.57 mm, dielectric constant $\varepsilon_r = 3.66$ and loss tangent of 0.004 to print. Roger RO 4350(tm) is used as the substrate material as it is light in weight and also have good mechanical strength with high performance. These properties make Roger RO 4350(tm) very attractive to be used as substrate.

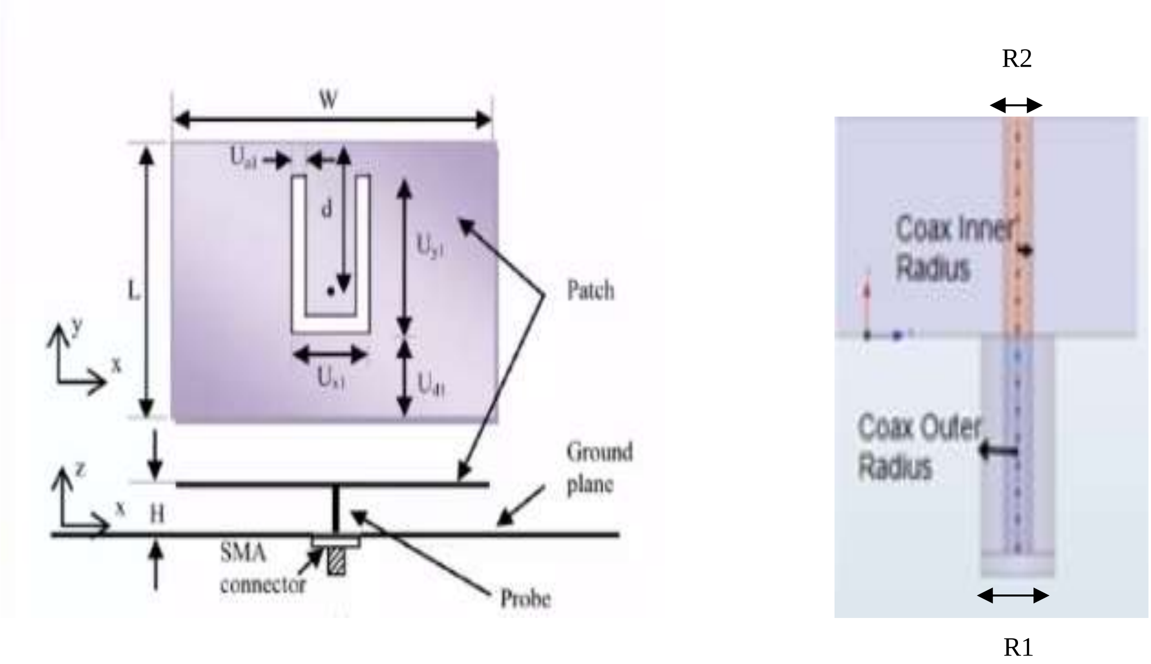

Fig.1 *Proposed dimentions of U-slot patch antenna*

The dimensions of the proposed structure is 15.8 mm × 13.1 mm × 1.57 mm. The proposed rectangular patch size is 4.24 mm × 2.45 mm. The feed point is 1.27mm from the centre of the patch. The slot thickness of proposed antenna is 0.25 mm. As the operating frequency is high,it needs to be designed with a simple structure; therefore, a microstrip coaxial feeding line is used. For this, radius of the inner coax is 0.009 mm, radius of the outer coax is 0.03 mm and coax feed length is 1.79 mm.

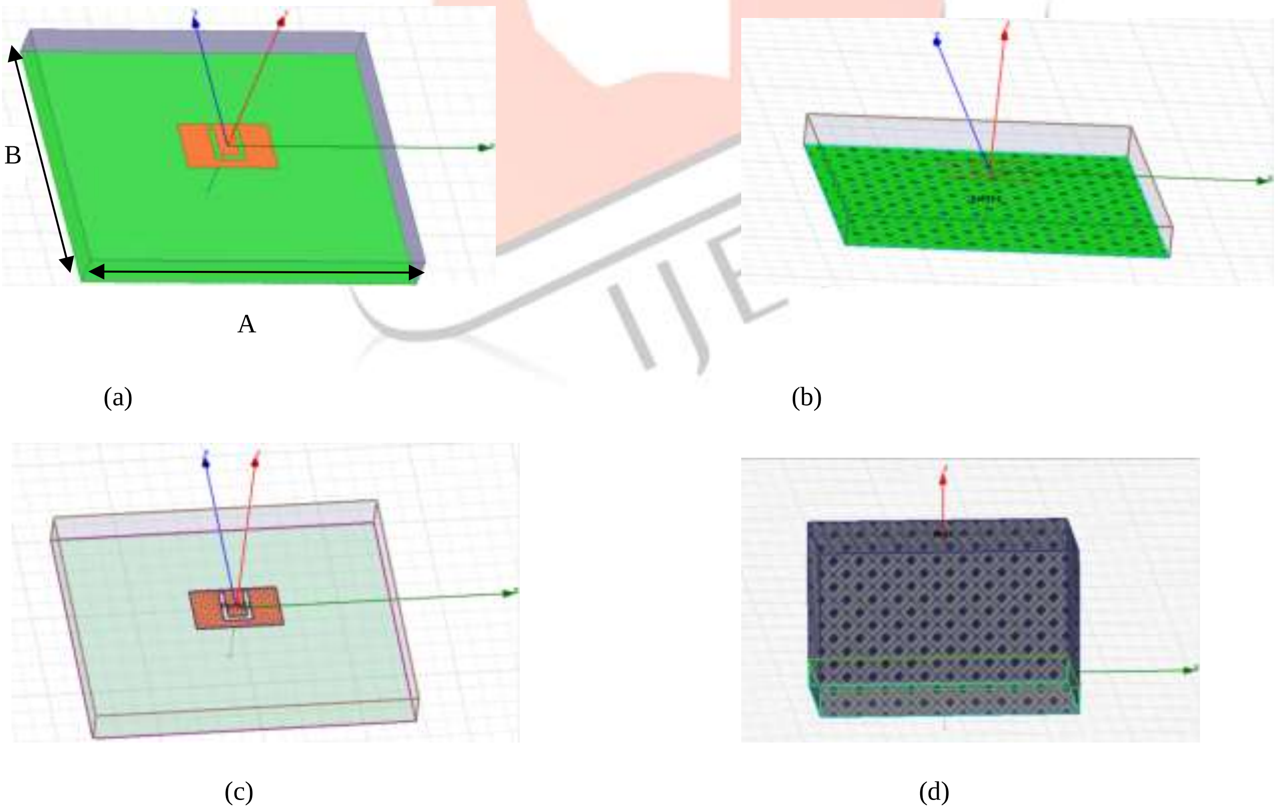

Fig.2 *(a) U-slot rectangular patch antenna, (b) Boundary at ground plane, (c) Boundary at patch. (d) Radiation boundary*

Fig.2 (a) is the proposed rectangular single-patch antenna with U-slot structure that is calculated and optimized using patch antenna equations [13]. Fig.2 (b) and (c) present the assigned boundary to ground plane and patch respectively. Fig. 4 (c) present radiation for air box to model free space radiation. A radiation boundary is used to emulate free space by truncating infinite free space to finite calculation domain. This minimize reflections from outer surfaces and ensures maximum absorption.

Table.1 *Optimized dimensions of Proposed Antenna*

Parameters	Size (mm)
Width of Substrate (A)	15.8
Length of Substrate (B)	13.1
Height of Substrate (H)	1.57
Width of Patch (W)	4.24
Length of the Patch (L)	2.45
Feed Point(d)	1.27
Distance between Slot and patch (U_{d1})	0.45
Width of the Slot (U_{x1})	1.43
Length of the Slot (U_{y1})	1.83
Thickness of the Slot (U_{a1})	0.25
Radius of outer coax (R1)	0.03
Radius of inner coax (R2)	0.009

III. RESULT AND DISCUSSION

The simulations of the antenna structure were performed using HFSS (High Frequency Structure Simulator) softwares. The antenna's performances are evaluated in terms of return loss, gain and VSWR and directivity. The valid radiating frequency of antenna is described by two measuring parameters of antenna that are the "return loss" And the "VSWR". If the return loss an antenna for specific frequency is more than -10 dB it indicates that whatever power fed to antenna out of maximum power is rejected. So, for a good radiating element, return loss should be less than -10 dB and VSWR is less than 2. Another useful measure describing the performance of an antenna is the gain. Although the gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. However, directivity is a measure that describes only the directional properties of the antenna, and it is therefore controlled only by the pattern.

Return loss

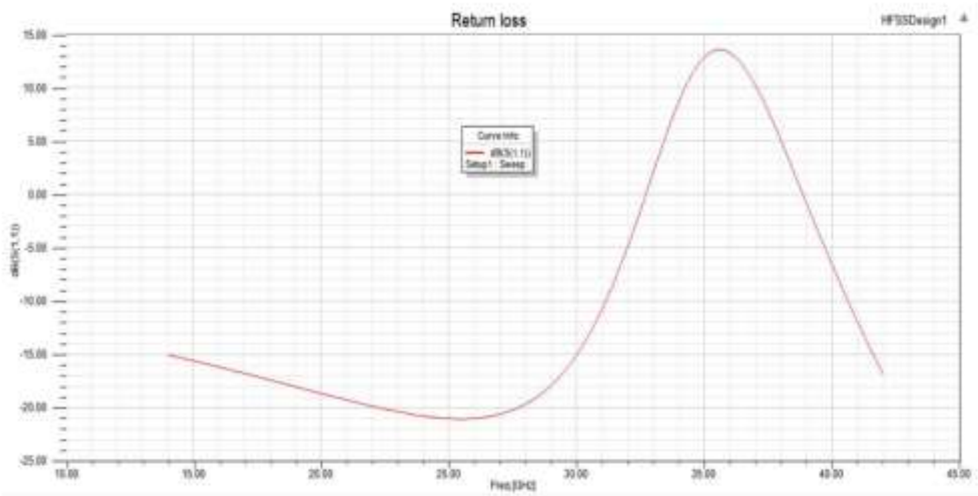

Fig.3 *Simulated resturn loss of the antenna*

Return loss is used to indicate the amount of power that is lost to load, and the lost power does not return as reflection. Return loss is an aspect similar to VSWR to be a sign of how well the matching between transmitter and antenna has taken place. Ideal value of return loss is approximately -13dB which corresponds to VSWR of less than 2. As shown in figure: 3 the value of Return loss is -20dB.

VSWR

The Voltage Standing Wave Ratio or VSWR is defined as the relation between the maximum voltage and the minimum voltage all along the transmission line. Further definition of the VSWR can be derived from the level of forward and reflected waves, it is also a sign of how capably or intimately an antenna's terminal input impedance is matched to the characteristic impedance of the transmission line.

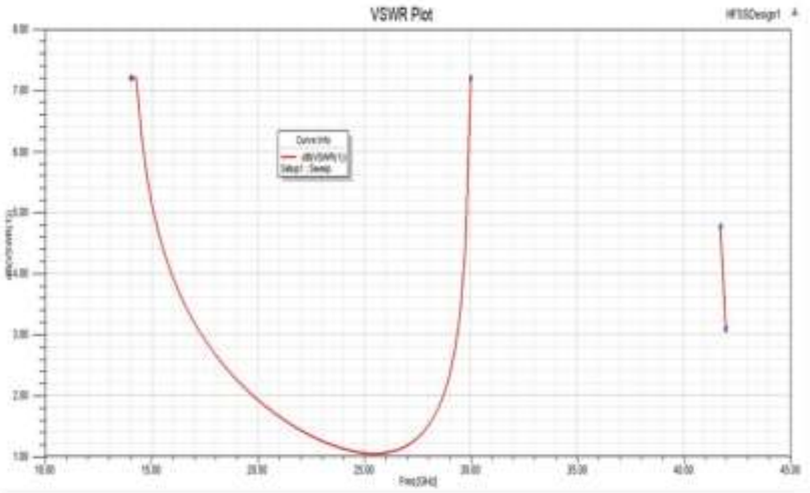

Fig.4 *VSWR of the antenna*

Also, VSWR and mismatch between the transmission line and antenna are directly proportional to each other that are when there is an increase in VSWR indicates an increase in the mismatch between the transmission line and antenna. As shown in figure: 4 the value of VSWR is 1. 02.

Gain

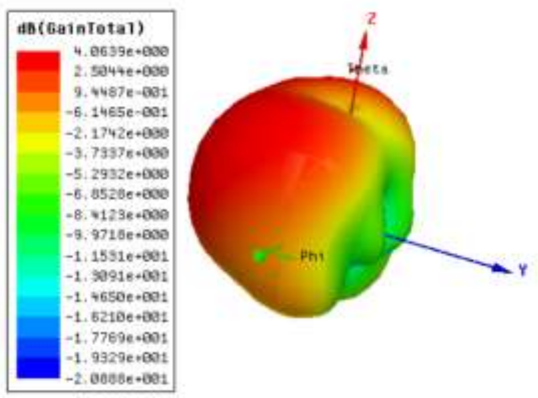

Fig.5 *Antenna's Gain at 28 GHz*

Gain of an antenna (in a given direction) is defined as "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. As shown in figure: 5 the value of Gain is 4.06 dB.

Radiation pattern

In many cases, the protocol of an H -plane and E -plane pattern or sweep is used in the presentation of antenna pattern data. The H -plane is the plane that contains the antenna's radiated magnetic field potential while the E -plane is the plane that contains the antenna's radiated electric field potential. These planes are always orthogonal. These quantitative aspects generally include the 3 dB beam width (1/2 power level), directivity, side lobe level and front to back ratio. The 3 dB beam width of antenna is simply a measure of the angular width of the -3 dB points on the antenna pattern relative to the pattern maximum.

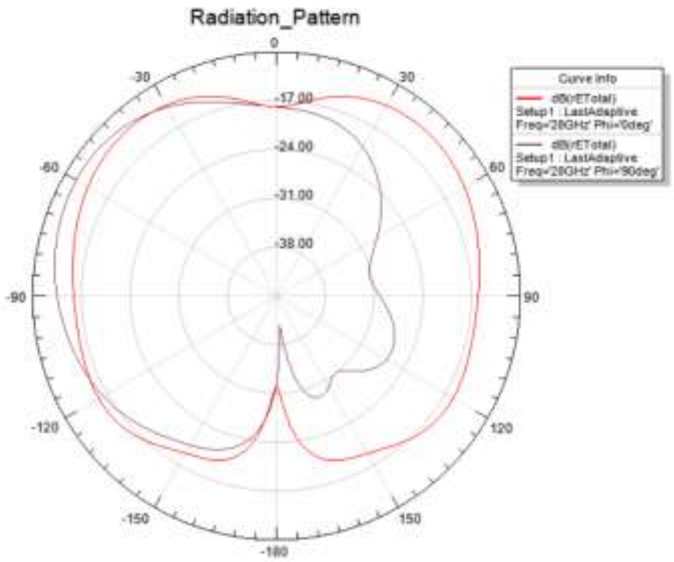

Fig.6 *Radiation Pattern at 28GHz*

Directivity

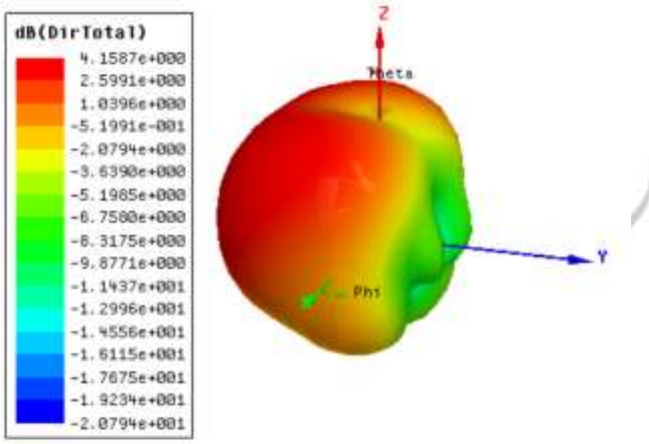

Fig.7 *Antenna's Directivity at 28 GHz*

The radiation patterns of an antenna provide the information that describes how the antenna directs the energy it radiates. As stated earlier, an antenna cannot radiate more total energy than is delivered to its input terminals. Antenna radiation patterns are typically presented in the form of a polar plot for a 360 degree angular pattern in one of two sweep planes. As shown in figure: 7 the value of Directivity is 4.15dB.

IV. CONCLUSION

In this paper, 4.24 mm × 2.45 mm micro strip antenna with U -shaped slot is designed and has been simulated using HFSS software. The operating frequency is around 28 GHz for a 5G system candidate. The simulated results showed very good with practical values. The proposed antenna have some favorable characteristics such as; compact size, almost symmetrical radiation pattern, higher gain, satisfactory return loss in desired frequency 28 GHz. Results & analysis of this antenna indicates that proposed antenna can be a good candidate for the 5G applications.

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