Use of Slots in Bandwidth Enhancement of Microstrip Patch Antenna for 5G Mobile Communication Networks

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Abstract. Recent studies have centered on finding the most effective methods for increasing the gain, directivity, and bandwidth of a microstrip patch antenna for usage in a variety of wireless applications. Microstrip patch antennas (MPAs) have been presented as a space-efficient and low-profile method of achieving a wide frequency range by employing slots of varying shapes. To demonstrate the concept behind the proposed antenna, parametric simulations were carried out. To increase bandwidth, many slots have been added. The slots are set up in the form of a word *RAED* on the patch. The Rogers RT Duroid 03003 substrate is used in both the design and simulation processes for the proposed antenna. This substrate has a standard thickness of 1.52 mm, a relative dielectric constant of 2.2, and a tangent loss of 0.0009 at the operating frequency. Simulated findings reveal a return loss of -62.247 dB, bandwidth of 11.031 GHz, and gain of 6.48 dBi at a central frequency of 28.427 GHz. The proposed antenna has a nearly 10-fold improvement in bandwidth over the MPA without the slots. This demonstrates how antenna slots greatly enhance gain and bandwidth. Therefore, the suggested antenna's compact design makes it well-suited for 5G mobile communication networks.

Keywords: Microstrip Patch Antenna, Broad Bandwidth, Slots.

1. Introduction

The increasing use of microwaves has led to a greater need for bandwidth in recent years [1-5]. Because of its portability, ease of integration, lightweight, and low profile, the microstrip patch antenna (MPA) has found applications in radar technology, space science, medicinal research, and wireless communication systems [6, 7]. Although MPAs have many advantages over traditional microwave antennas, they nevertheless have their drawbacks. These include poor gain, significant ohmic loss in the array, and the majority of the energy being

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radiated into space. The biggest problem that prevents MPAs from being widely used is their limited and/or narrow bandwidth. Over time, wireless communication has grown significantly due to the need for exceptionally high throughput and more efficient communication technology. Fifth-generation (5G) base stations, in comparison to their fourth-generation (4G) counterparts, require more and higher bandwidth from mobile devices [8]. To achieve the design flexibility, high gain, and expanded operating bandwidth required by 5G [8, 9], it will be necessary to improve and/or upgrade antenna systems since 5G communications necessitate more bandwidth, and many different frequency bands can be used [10]. These include 28 GHz, 38 GHz, V band, and E band (71-76 GHz, 81-86 GHz, and 91-93 GHz). 5G's initial deployment will focus on the 680 MHz, 3.5 GHz, and 26/28 GHz bands [11]. As a result, a wide variety of methods for facilitating 5G communication have been proposed. Improvements in performance characteristics to meet the requirements of 5G technology have been implemented using a variety of methods, including the slots technique, antenna array technique, defective ground plane structure, and metamaterial [12]-[14]. An essential part of the fifth-generation mobile network is the millimeter-wave (mm-Wave) antenna. Because of its portability, low weight, and ease of integration, microstrip antennas have found widespread use in many different wireless applications, including those in aviation, satellite communication, missiles, and even medicine [15]-[20]. Numerous studies have been done to make use of it, even though it has the drawback of reduced and lower bandwidth, which can be improved by employing various devised ways and methods [21], [22]. A variety of strategies have been proposed over the years to increase the bandwidth of MPAs. These strategies include; increasing the substrate thickness, decreasing the substrate dielectric constant, loading the chip with a resistor, utilizing parasitic patches in both single and multi-layer configurations, making use of electromagnetic band gap structures, and making use of a backed edge-fed cavity [23]. Most MPAs, however, are created by piling on more components, increasing the complexity of their original designs. There has been some recent success in using complementary structures in the construction of microwave devices [24]. Broadening an antenna's frequency range can be achieved in a number of straightforward methods, one of which is by increasing the substrate's thickness to accommodate higher power surface waves and lower radiation power. Adding two or more slots to the radiating patch is another way to modify the geometry patch and boost or improve the bandwidth [25]. The Federal Communication Commission (FCC) recommended using millimeter-wave frequency in designing the 5G antenna. The Federal Communications Commission (FCC) has proposed a new rule (FCC 15-138) for wireless broadband frequencies, including the 28 GHz frequency band, the 37 GHz frequency band, the 38 GHz frequency band, and the 64-71 GHz frequency band [26]. Due to the narrowness of the gap between 28 GHz and 38 GHz, this frequency range is being eyed for 5G applications [27]. Due to their compact size, low profile, and ease of fabrication, microstrip antenna types are frequently used in the development of antennas for 5G technology applications. However, microstrip antennas have a limited frequency range and lower gain. Consequently, many methods have been looked at with the hopes of enhancing the bandwidth and gain performance of the microstrip antenna. These methods include the use of metamaterial structures, patch-slot modifications, and defective ground structures (DGS). For frequencies between 14.4 and 15.4 GHz, antenna arrays designed using the U-slot approach have shown increases in bandwidth of up to 300 MHz [28], 20-30% impedance, and gain bandwidths without parasitic patches on either the same or opposite layer [29]. In addition, the bandwidth can be increased by as much as 63.61 percent when utilizing the stepped-cut four corners approach [30], and up to 2.9 GHz when using the stepped-line-cut method in conjunction with the triangular slot method in the patch [31] for ultra-wideband antenna applications.

2. Design and Simulation of Microstrip Patch Antenna with and without Slots

The design and simulation results for the single-element microstrip patch antennas are discussed. Computer simulation technology (CST) microwave studio 2022 software is used to evaluate the proposed design's antenna element. The antenna is often implemented on a Rogers 03003 substrate, which has a dielectric constant of 2.2, a loss tangent of 0.0009, and a thickness of 1.52 mm. This section is to design a single-element microstrip patch antenna. The single element consists of a radiating patch, feeding line, substrate, and ground plane. SMA connector is used to connect the inset feed line. The effect of the reflection coefficient, bandwidth, directivity, and other simulation parameters have clearly been observed. The antenna is first designed to resonate at 28 GHz with an achievable reflection coefficient, bandwidth, and gain as shown in Figure 1. The slots termed RAED is then introduced at the center of the patch to increase and/or enhance the bandwidth of the antenna. Table I shows the parameter representation of the proposed microstrip patch antenna.

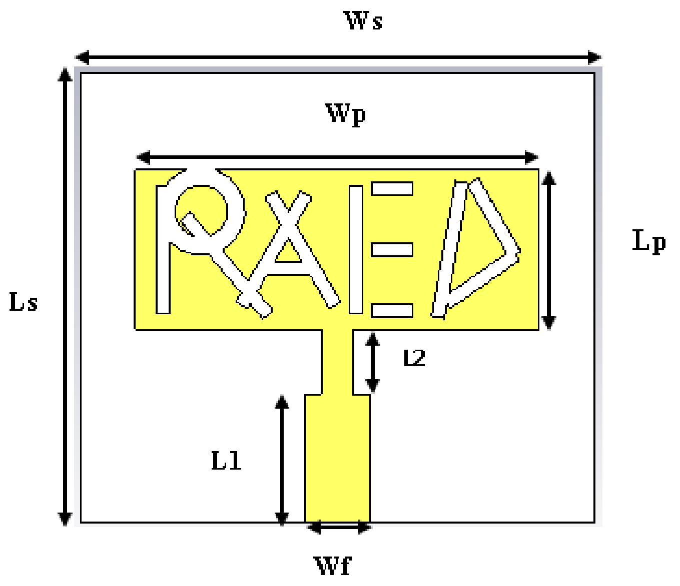

Fig. 1: Schematic Diagram of the proposed Microstrip Patch Antenna with Slots **(RAED)**

Table 1. Dimensions of the Proposed Microstrip Patch Antenna

Parameters	Dimensions (mm)
Width of the substrate Ws	8
Length of the substate Ls	7
Inner/outer Radius of slot R R1/R2	u/0.6*u

Antenna patch width Wp	6.278
Antenna patch length Lp	2.50
Width of the feeding Wf	1.10
Length of feed L1	2.00
Slot width U	0.6842
Slot length V	2.00
Length of feed L2	1.00

From the schematic representation of the patch antenna, it can be observed that the antenna has the following alphabetical shapes as slots within the patch front denoted as **R, A, E, and D**: R is designed in a cylindrical shape with u and 0.6*u as the inner and outer radius and v as the slot length as well as u as the slot width, all the remaining A, E and D are formed using either v as the length and u as the width using small fractions to reduce or increase the length. This slot RAED is used to enhance the bandwidth of the proposed microstrip patch antenna resonating at 28 GHz.

3. Results and Discussions

The proposed microstrip patch antenna was simulated using CST MWS studio software. The antenna is employed using Rogers 03003 as a substrate which has a dielectric constant of 2.2, a loss tangent of 0.0009, and a thickness of 1.52 mm. Figure 2 shows the simulated reflection coefficient (S11) of the proposed antenna at 28.427 GHz with S11= -62.245dB and an enhanced impedance bandwidth of 11.031 GHz (24.188 – 35.218 GHz) respectively. Figure 3 shows the simulated 3D pattern of the proposed antenna with a recorded gain of 6.48 dBi at 28.427GHz. However, this antenna is small, compact, and simple in design. It is clearly observed that, by introduction and/or use of slots termed **RAED** in the forefront of the patch, the antenna bandwidth has been enhanced to an ultrawideband covering from 24.188 – 35.218 GHz.

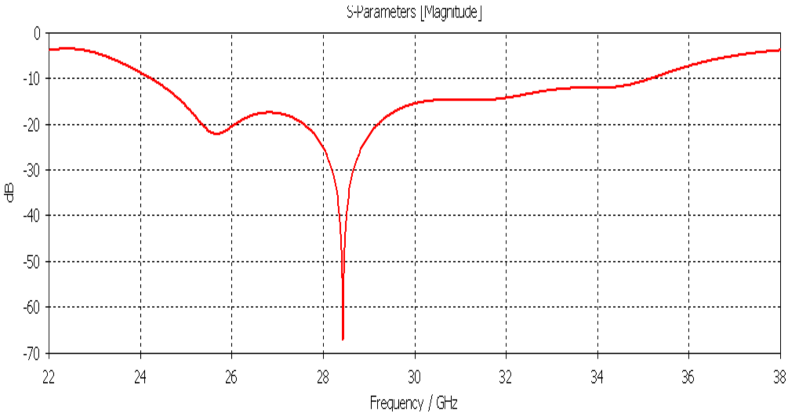

Fig. 2. Simulated Reflection Coefficient, S_{11}

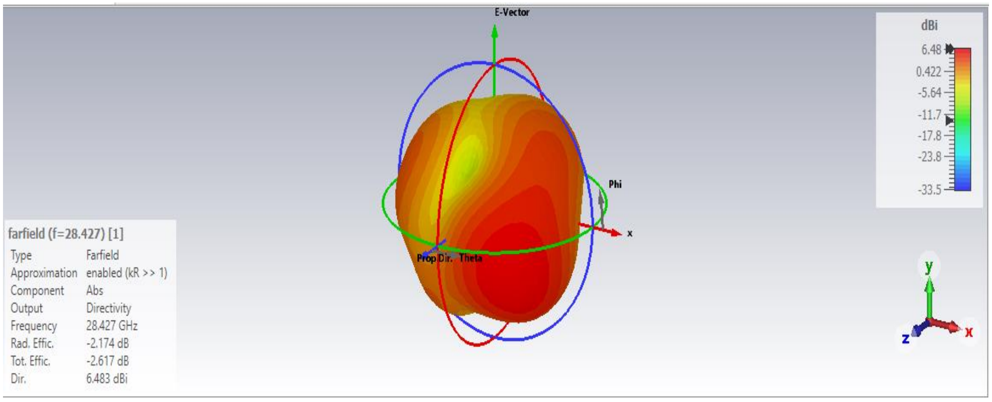
farfield (f=28.427) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 28.427 GHz
Rad. Effic. -2.174 dB
Tot. Effic. -2.617 dB
Dir. 6.483 dBi

Fig. 3. Gain of the proposed Antenna at 28.427 GHz

After comparing the results to those of prior works, as shown in Table 2, it is found that the suggested microstrip patch antenna outperforms the others in terms of bandwidth, reflection coefficient, and directivity and that its gain is 6.48 dBi at 28.427 GHz. The antenna's summary performance parameters are summarized in Table 2 below. These metrics include center frequency, reflection coefficient, directional gain, and bandwidth.

Table 2. Proposed Microstrip Patch Antenna Compared with Previous Works

Ref	Central Frequency (GHz)	S11 (dB)	Bandwidth (GHz)	Directivity (dBi)
19	27	-42.60	1.63	10.95
8	28	-35.60	2.20	12.87
12	28	-30.71	2.68	9.870
This Work	28.4	-62.25	11.03	6.48

4. Conclusion

This paper presents the use of slots in bandwidth enhancement of microstrip patch antenna for 5G mobile communication networks. The antenna is designed on Rogers 03003substrate of thickness of 1.52 mm and dielectric constant of 2.2. The antenna is first designed to resonate at 28 GHz before introducing or using slots termed **RAED** on the patch to enhance the bandwidth of the antenna. The maximum directivity achieved has been recorded as 6.48 dBi, meanwhile, the -10dB impedance bandwidth is obtained as 11.03 GHz at 28.427 GHz respectively. Hence, the antenna has potential as a component in 5G mobile networks. The proposed antenna has a nearly 10-fold improvement in bandwidth over the MPA without the slots. This indicates that the use of slots greatly enhances gain and bandwidth. Therefore, the suggested antenna's compact design makes it well-suited for 5G mobile communication networks.

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