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Research Article

Compact Microstrip Antenna Design for 5G Communication in Millimeter Wave at 28 GHz

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Abstract

In this study, we proposed a compact microstrip monopole antenna, can operating in millimeter wave communication. It is consisted of FR4 with thickness of 1.6mm and it was designed as planar-fed single-band by placing rectangular slots on square patch, as a simple and compact structure. Thus, the proposed antenna was simulated in the Ansys HFSS module and various antenna parameters such as radiation performance and antenna gain were obtained in a single frequency range. The return-loss bandwidth was measured as 716 MHz centering at 28 GHz, covering the required bandwidth of 5G standard, as a reference of -10 dB..

Keywords: Rectangle slots, square patch, millimeter wave, 5G wireless application, single band microstrip patch antenna.

28 GHz'de Milimetre Dalgada 5G Haberleşme için Kompakt Mikroşerit Anten Tasarımı

Öz

Bu çalışmada, milimetre dalga haberleşmesinde çalışabilen kompakt bir mikroşerit monopole anten önerilmiştir. Anten, 1,6mm kalınlığında FR4 plaka üzerinde olup, düzlemsel beslemeli kare yama üzerine dikdörtgen yarıklar açılarak, basit ve kompakt bir yapıda tek bantlı olarak tasarlanmıştır. Bu yüzden, önerilen anten Ansys HFSS modülünde simüle edilmiştir, istenen frekans aralığı için ışıma performansı ve anten kazancı gibi çeşitli anten parametreleri elde edilmiştir. -10 dB değeri referans olarak alındığında bant genişliği 28 GHz merkez frekansında 716 MHz olarak ölçülmüştür ki bu 5G standardı için gereken bant genişliğini kapsamaktadır.

Anahtar Kelimeler: Dikdörtgen yarıklar, kare yama, milimetre dalga, 5G kablosuz uygulama, tek bantlı mikroşerit yama anteni.

1. Introduction

Nowadays, there is rapidly increasing demand for high data rates in wireless communication. Mobile communication technology continues its evolution from 1G to 5G. Unfortunately, the currently used 4G mobile technology cannot meet the needs of the end users. Mentioned mobile communication generations have been insufficient to solve problems such as weak quality, crowded channel, insufficient coverage, flexibility and failed connection (Churi et al., 2002; Akhtar, 2000; Mondal et al., 2015; Abiramy, 2017;). In order to overcome these problems, 5G mobile communication

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technology is being researched and developed every day. Standardization efforts were finalized in 2017 and it is predicted commercialized in 2020 (Fagbohun, 2014; Vaibhav et al. 2017). 5G mobile communication technology has various advantages. The most important advantages are the high energy efficiency, high security property, great bandwidth, and allows a large number of users to operate at a very high speed at the same time as one gigabit. 5G mobile communication technology provides rich multimedia service support, such as teleconferencing applications and interactive games (Kumar et al. 2016; Sapakal et al. 2013). There are candidate frequency bands such as below 6 GHz and millimeter wave for 5G mobile communication technology. The main purpose of mobile communication systems is to collect data, as with all wireless communication systems. For this purpose, antenna design plays a very important role and antenna parameters such as bandwidth, beam width and gain can affect the overall system performance. Antennas designed for use on mobile devices must be lightweight, small, easy to fabricated and fit into the mobile phone's allocated section for antenna (Balanis, 1998). Microstrip patch antennas (MPAs) can meet the requirements of both wireless communication systems and mobile communication systems. In addition, these antennas have advantageous features such as used on planar and non-planar surfaces, used in multi-band, and low cost (Balanis, 1998; Abirami, 2017; Saini et al., 2017; Ali et al., 2016; Alvarez et al., 2015; Alam et al., 2013; Chen et al., 2013). Although it is predicted that FR4 MPAs will not provide healthy results in bands above 6 GHz, MPAs have been observed to operate stable in millimeter wave band under appropriate measurement conditions (Kaeib, 2019; Ojaroudiparchin, 2015). In this study, an antenna design has been proposed which is operating in 28 GHz frequency band. With this proposed antenna concept, ultra-wide bandwidth has been achieved, which enables data transfer at high speeds. In this MPA design, the rectangular slots loaded on the square shaped patch are shown. The offered antenna uses a planar feed and is simulated with High Frequency Structural Simulator (HFSS) software (Cendes, 2016).

2. Design of the Antenna

In general, because of it has only one resonance, microstrip antenna bandwidth is not very wide. Therefore, to design a wideband antenna, minimum two resonant parts are needed as each one operating at desired resonance frequency. So, wideband or multiband performance can be obtained by overlapping of these resonances. To obtain wide bandwidth with a single resonance band so, this design was chosen.

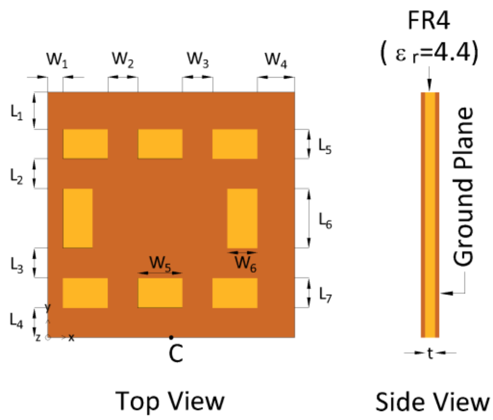

Figure 1. Dimensions of the antenna.

Additionally, in this design as in the traditional UWB monopole antenna was deployed a solid ground plane, on the other side as shown in Fig. 1. Achieving wideband together with good impedance matching over the whole operating band, the above design abilities are offered. The basis of the monopole radiation is a square-shaped patch with an edge length of 8.24 mm. There are two types of slots on the square patch. The first is the vertical slots, the second is the horizontal slots. Each vertical slots are identical and are represented by the length L6 and the width W6 and likewise each horizontal slots are identical and are represented by the length L5 and the width W5. The ground plane of the antenna is a solid rectangular plane as in general microstrip-fed monopole antennas. This simple geometry also facilitates the production of the proposed antenna. Entire size of the antenna has been expressed in mm, and dimensions of ground plane 8.24 mm and 8.24 mm, length and width respectively. The width of the excitation feedline was chosen 0.5 mm to minimize the return loss by providing 50 Ω characteristic impedance.

The slots are placed on the radiating plane (the front face of the substrate) to obtain the desired antenna parameters. FR4 substrate with a thickness of 1.6 mm was used to avoid any coupling between the radiating plane and the ground plane. In Table 1 all dimensions of the recommended broadband antenna are sorted. The antenna could not be produced due to lack of laboratory facilities. This wideband antenna was designed on an FR-4 substrate with 1.6 mm-thick, a loss tangent of 0.024, permittivity of 4.4.

Table 1. Antenna parameters

Parameter	**mm**	**Parameter**	**mm**
L_1	1.24	W_1	0.5
L_2	1	W_2	1
L_3	1	W_3	1
L_4	1	W_4	1.24
L_5	1	W_5	1.5
L_6	2	W_6	1
L_7	1	t	1.6

To research and optimize the presented antenna configuration numerically, finite element analysis based on Ansoft HFSS is used. Optimized parameters of designed antenna are seen on Table I. The return loss of proposed antenna seen in Fig. 7. The simulation result clearly shows that the proposed antenna has a resonance at 28 GHz and has a 716 MHz bandwidth in the same band. Obviously, with reference to -10 dB, the bandwidth covers the entire spectrum from 27.63 to 28.36 GHz. The effects of the vertical slots, horizontal slots and all slots on the traditional square patch without any changes in the ground plane were examined and analyzed in Fig. 7. In these cases, remember that all non-mentioned dimensions are the same as those listed in Table 1. In the case of the vertical slot, the resonances are seen at 21.77 and 28.22 GHz, respectively, and the return loss values are -13.64 dB and -31.38 dB, respectively, as reference -10 dB. In the case of the horizontal slot, the resonance frequencies of the microstrip patch antenna are 21.80 and 28.13 GHz, respectively, so it’s differ from the desired resonance frequency. Eventually, it is observed that in the case of rectangular slots on the square shaped patch, the return loss values are -12.47 dB and -26.49 dB so these are good competitors, and the proposed design has resonant frequencies at 21.77 and 28 GHz, respectively.

2.1. Change in Vertical Slot Parameters

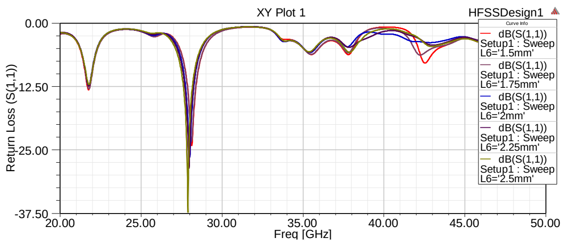

Figure 2. The simulation result of the return loss

against the frequency for the various L_6 values in the proposed antenna, other parameters were kept constant.

The L_6 length of the vertical slot of the proposed antenna is simulated between 1.5 and 2.5 mm and the results are given in Fig. 2. In case of the length is 1.5 and 1.75 mm, resonances are not observed as desired frequency. Also the return loss values are relatively low. Similarly, in case of the length is 2.25 and 2.50 mm, resonances are not observed as desired frequency but the return loss values are good. 2 mm are preferred because of the resonance at the desired frequency and good return loss value.

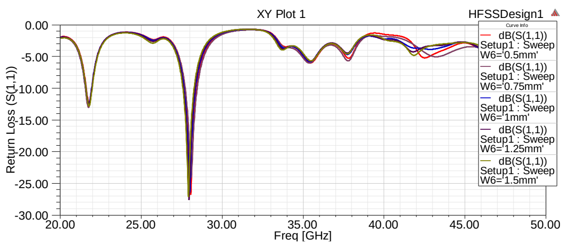

Figure 3. The simulation result of the return loss against the frequency for the various W6 values in the proposed antenna, other parameters were kept constant.

The W_6 width of the vertical slot of the proposed antenna is simulated between 0.5 and 1.5 mm and the results are given in Fig. 3. In case of the selected width value is not 1 mm, a small amount of shifts in the desired resonance frequency was observed. Also, there was slight variations in bandwidth and in the return loss. Considering all parameters, the width of the vertical slot, W_6 was decided to be 1 mm.

2.2. Change in Horizontal Slot Parameters

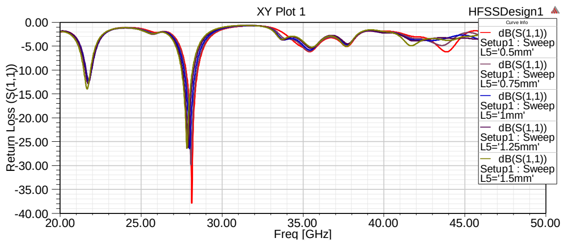

Figure 4. The simulation result of the return loss against the frequency for the various L_5 values in the proposed antenna, other parameters were kept constant.

The L_5 length of the horizontal slot of the proposed antenna is simulated between 0.5 and 1.5 mm and the results are given in Fig 4. In the case of the length of the horizontal slot is 0.5 and 0.75 mm, it was observed that the bandwidth increased but not resonating at the desired frequency. Similarly, in the case of 1.25 and 1.50 mm, it was observed that the resonance frequency of the proposed antenna differs from the desired resonance frequency and the bandwidth is reduced. As can be seen from Fig. 4, the length of the horizontal slot is selected as 1 mm to achieve both the maximum bandwidth and the desired resonance frequency.

The W_5 width of the horizontal slot of the proposed antenna is simulated between 1 and 2 mm and the results are given in Fig. 5. In the case of the width of the horizontal slot is 1 and 1.25 mm, it was observed that the bandwidth increased but not resonating at the desired frequency. Similarly, in the case of 1.75 and 2 mm, it was observed that the resonance frequency of the proposed antenna differs from the desired resonance frequency and the bandwidth is reduced. If the simulation result is carefully examined, in terms of bandwidth and resonance frequency, it will be seen that the best performance will be obtained if the width of horizontal slot is 1.5 mm.

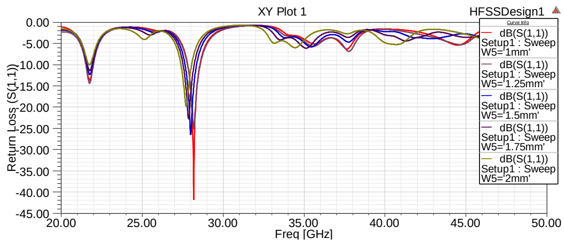

Figure 5. The simulation result of the return loss against the frequency for the various W5 values in the proposed antenna, other parameters were kept constant.

2.3. Change of Size in Ground Plane

The presented antenna is simulated by changing the ground plane length from 5.24 to 8.24 mm and Fig. 6 is shown. When the ground plane length is different from 8.24 mm, it is seen that the antenna is not resonating in the desired frequency band and the return loss value decreases (especially in cases of 5.24 and 6.24 mm it cannot exceed -20 dB). A decrease in the return loss value means that there is a mismatch in the input impedance of the antenna. In addition, in cases of 6.24 and 7.24 mm the bandwidth increased. Clearly, the optimum ground plane length is 8.24 mm due to has resonance at desired frequency band and input impedance matching.

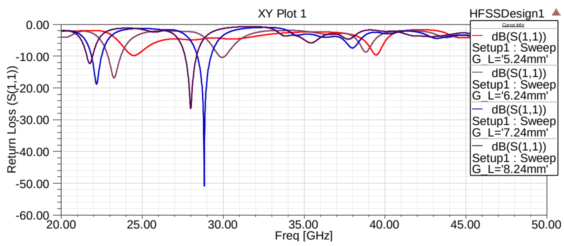

Figure 6. The simulation result of the return loss against the frequency for the various ground plane length in the proposed antenna, other parameters were kept constant.

3. Result and Discussion

The performance of the compact microstrip patch antenna obtained by placing the rectangular slots on square patch is tested by means of the HFSS software. Various antenna parameters, such as Return loss, VSWR, Radiation pattern and Gain, were analyzed in the frequency range of 23 to 33 GHz. The patch antenna was shown to resonate at one frequency with reference to -10 dB. Analysis results are shown in the figures.

Table 2. Proposed antenna's return loss and bandwidth.

Resonant Frequency (GHz)	Band covered	Return loss (dB)	Bandwidth (MHz)
28	Ka	-20.26	656

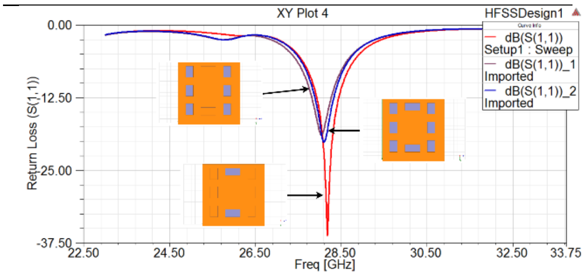

Figure 7. Simulation result of the proposed antenna, vertical slots, horizontal slots and the final shape.

The proposed antenna has one resonance frequency in the frequency range 23 to 33 GHz when analyzed according to the return loss parameter. At the desired center frequency of 28 GHz, the return loss value is observed to be -20.26 dB. Between two points with return loss values -10 dB around the center frequency, the bandwidth is found 656 MHz. The proposed antenna resonates in the frequency range of 27.64 to 28.30 GHz, which corresponds to the millimeter communication. The above-mentioned parameters, such as the resonance frequency and to it corresponding band, return loss and bandwidth, are shown in Table 2.

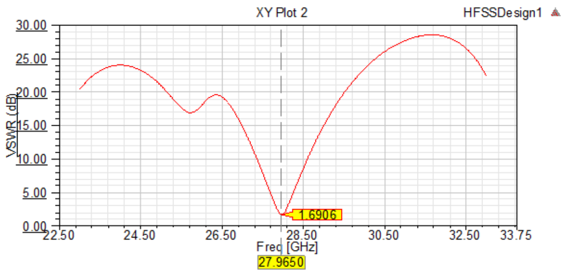

Figure 8. Proposed antenna's voltage standing wave ratio.

Back reflections arising from the empadans difference between the transmission line and the load are called VSWR. VSWR also represents RF power transmission efficiency from power source to load, via a trans mission line. The proposed antenna design's VSWR parameter is shown in Fig. 8. Obviously the VSWR value at the desired frequency is about 1.69 dB, which proves to be a excellent matching.

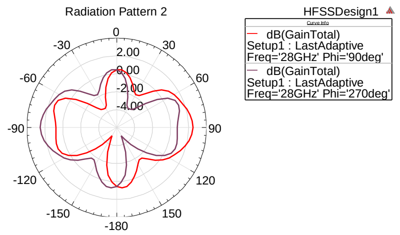

Figure 9. Proposed antenna's directivity at 28 GHz in E-plane.

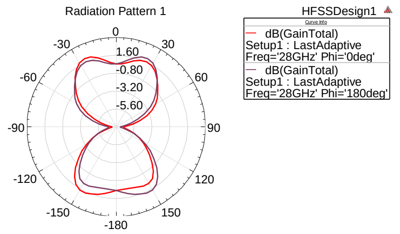

Figure 10. Proposed antenna's directivity at 28 GHz in H-plane.

Table 3. Proposed antenna's directivity in E and H plane at resonance frequency.

Resonant Frequency (GHz)	Directivity in E plane (dB)	Directivity in H plane (dB)
28	3.42	5.33

Directivity is a term that expresses how strong the antenna radiation is in certain selected directions. The presented antenna directivity at 28 GHz in E and H plane as shown in Fig. 9 and Fig. 10 respectively. The figure shows φ= 0 and φ= 90 degrees states of the radiation pattern. The directivity values at 28 GHz for the offered antenna are given in Table 3.

The ratio of the power density of a directional antenna at one point to the power density at the same point of the non-directional antenna fed by the same power is defined as the gain of the directional antenna at that point. Due to MPAs advantageous properties, are used in a wide variety of applications, but they have two major disadvantages, such as narrow bandwidth and low gain. The proposed antenna gain within the range of 23 to 33 GHz is shown in Fig. 11. Although, the gain at central frequency 28 GHz is low, the bandwidth in resonance frequency is ultra wideband.

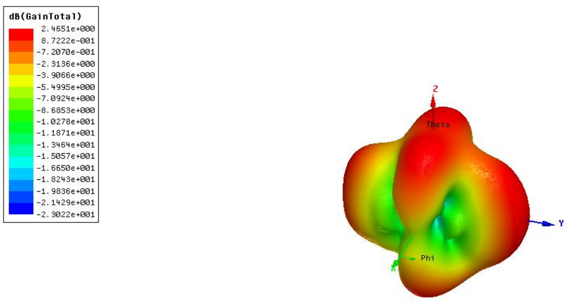

Figure 11. Proposed antenna's gain.

4. Conclusion

In this study, a compact microstrip antenna is designed an electrically small and slot-loaded rectangular patch to operate in a single band. This antenna can be used in modern communication systems, especially in wireless communication. Satisfactory gain was acquired in this antenna on resonant frequency. Also resonance frequency is within the Ka band frequency range. Additionaly, the gain and directivity are pretty affecting. The size of the proposed

MPA is small and compact in order to get the desired resonance frequency. The presented antenna has 1.6 mm thick, although utilizing the FR4 substrate. We suggest that our prototype antenna will work very well in millimeter wave communication. Designing an MPA by placing rectangular slots on a square patch is quite different from the other millimeter wave antennas in the literature.

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