Indonesian Journal of Electrical Engineering and Computer Science
Vol. 19, No. 3, September 2020, pp. 1367~1374
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v19.i3.pp1367-1374

Power density of rectangular microstrip patch antenna arrays for 5G indoor base station

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Article Info

Article history:

Received Feb 5, 2020
Revised Mar 26, 2020
Accepted Apr 12, 2020

Keywords:

5G
Antenna arrays
Microstrip patch
Millimeter wave
Power density

ABSTRACT

The fifth-generation (5G) network has been broadly investigated by many researchers. The capabilities of 5G include massive system capacity, incredibly high data rates everywhere, very low latency and the most important point is that it is exceptionally low device cost and low energy consumption. A key technology of 5G is the millimeter wave operating at 28 GHz and 38 GHz frequency bands which enable massive MIMO and small cell base station densification. However, there has been public concern associated with human exposure to electromagnetic fields (EMF) from 5G communication devices. Hence, this paper studies the power density of a 5G antenna array that can be used for the indoor base station. The power density is the amount of power or signal strength absorbed by a receiver such as the human body located a distance from the base station. To achieve this, the design of array antennas using CST software at 28 GHz, fabrication and measurement were carried out in an indoor and hallway environment. The measurement processes were set up at IC5G at UTM Kuala Lumpur in which the distance of the transmitter to receiver where 1 m, 4 m, 8 m, and 10 m. In this study, the measured power density is found to be below the set limit by the International Commission on Non-Ionizing Radiation Protection and hence no health implication is feared. Regardless, sufficient act of cautionary has to be applied by those staying close to small cell base stations and more studies are still needed to ensure the safety of use of 5G base stations.

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1. INTRODUCTION

The increasing numbers of antennas on the cellular base station towers have caused the public to be concerned about human exposure to electromagnetic fields (EMF) and various health effects [1]. Antennas are presumably one of the most taken for granted components in wireless and cellular communication systems. Nevertheless, they are exceptionally critical to the operation of a cellular base station with many choices available depending upon the particular site and operating environment [2]. Physical quantities such as the Specific Absorption Rate (SAR), magnetic field strength, electric field strength, and power density are used to specify Electromagnetic (EM) radiation exposure. There are two types of limit exposure specified by standard bodies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Federal Communication Commission (FCC), and the division is for occupational and public exposure [3]. Occupational exposure indicates the EM exposure of adults who have been trained and who are aware of the potential hazards and hence, take the necessary precaution [4]. On the other hand, public exposure consists of people of all ages.

When the first-generation mobile service was initiated, most mobile base station was installed on antenna towers that were taller than 30 m [5]. However, the increase in the demand for mobile data has brought about small cell densification with base stations that can be located closer to buildings. For example, the study in [6-8], worked on the application of the different types of antennas for the indoor base station. However, these works [9, 10], did not discuss the power density for the indoor base station antennas. The rapid development of location systems has made indoor locating systems are quite popular and widespread such that they find lots of commercial applications [11]. The exposure limit for power density for ICNIRP for frequency above 10 GHz is 10 W/m2, 50 W/m2 for public and occupational values, respectively. The power density of the FCC for frequency above 6 GHz is 10 W/m2 for public value [12].

The purpose of this paper is to study the power density of antenna arrays that can be used for the indoor base station in the 5G frequency range. Hence, the design low-cost array of rectangular microstrip patches antennas at 28 GHz is presented. 28 GHz is one of the standard frequency of 5G communication [13]. This includes a single, 2x2, 4x4 and 8x8 antenna arrays designed, fabricated and tested in an indoor and hallway environment. The dimensions of the antenna are extremely important when indoor measurements are performed due to available space [14]. The result shows that the power density is inversely proportional to the distance and the power density of the indoor is slightly higher compared to the hallway for all the antennas measured. In addition, higher power density is obtained from the 8x8 antenna array compared to the 4x4, 2x2 and single antenna both in the indoor and hallway environment and below exposure limits set by ICNIRP.

The rest of this paper is structured as follows: Section 2 discusses the related work; Section 3 covers the mathematical formulation and equations on power density. In Section 4, the methodology is presented, and Section 5 is on the results and discussion. Finally, Section 6 concludes the paper.

2. RELATED WORKS

The study in [15] explored the emission of electromagnetic radiation from a cellular base station. The results show that power density was low in kitchen and hall, medium in bedrooms and high in rooftops and balcony where the base station was installed at the opposite building. Power density and electric field changes in accordance with a number of voice calls, the height of the antenna and distance from base station antenna tower. From [16] stated that the calculation to measure the compliance distance from the mobile base station has been done and it is discovered that for operating frequency GSM 1800, the safest distance from the base station from a human is around 8.4 metre. The paper reference [17] affirmed that for National Radiological Protection Board (NRPB) guidelines the compliance distance does not exceed 3.1 metre for GSM 900, whereas compliance for GSM 1800 does not exceed 2.1 metre. Furthermore, the paper also declared that for ICNIRP guidelines, their compliance distance is different from NRPB guidelines, in which the compliance distance does not exceed 8.4 metre for GSM 900, while for GSM 1800 the compliance distance does not exceed 6.7 metre. Compliance distance in other directions, such as above and below the antennas, would be smaller. Most of this work focused on 4G radiofrequency. Recent studies have investigated the effects of 5G frequency in [18, 19], by considering frequencies above 6 GHz. The authors in [18] focused on the different methods for measurement of compliance distance for a user equipment for 5G at 15 GHz while [19] investigated the maximum power spatially power density for a uniform patch array 8x1 antenna. This existing work focused on the EMF compliance for the user equipment. In this work, we focus on the power density for an indoor base station. Different arrays of antenna are examined at 28 GHz and in different environments.

3. FORMULA AND EQUATIONS

According to [16], from field theory, the electric and magnetic field intensities at the far-field or Fraunhofer region in free space are always in phase and mutually perpendicular to each other. The power intensity carried by these two waves at the observation point is given by the Poynting vector.

$$\bar{P} = \mathrm{Re}\ (\bar{E} \times \bar{H}^*) \text{ watts/unit area} \tag{1}$$

Where $\bar{E}$ is the electric intensity in volt per unit length, $\bar{H}$ is the magnetic intensity in ampere per unit length, Re indicates the real part, and * stands for the complex conjugate, and both E and H are complex quantities. At the far field, the electric and magnetic fields are related by the relationship [20].

$$\eta_0 = \frac{E}{H}\ \Omega \tag{2}$$

The free-space attenuation is different from the dissipative attenuation of a medium such as air which absorbs energy from the wave. The power density in a spherical wave must decrease with distance as the energy in the wave spreads out over an ever-increasing surface as the wave progresses. Figure 1 illustrates the situation.

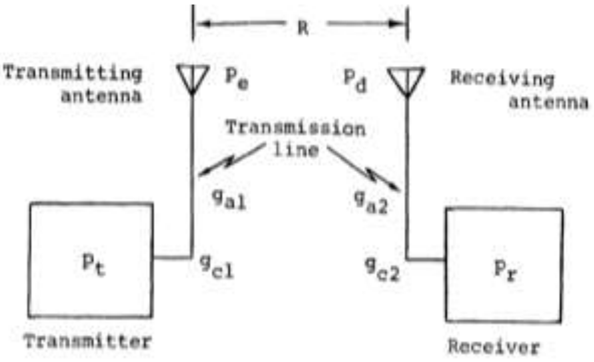


Figure 1. Free space attenuation [16]

The receiver power is equal to the power density at the antenna head times at the aperture of the receiving antenna, the antenna gain, and the cable loss. The power density at the receiving antenna is equal to the transmitter power times the antenna gain, the cable loss, and then divided by the spherical surface area. Therefore, the receiving power can be expressed by

$$P_r = \left(\frac{P_e}{4\pi R^2}\right)\left(\frac{\lambda^2}{4\pi}\right)g_{a2}g_{c2}$$

$$= P_t g_{a1} g_{c1} g_{a2} g_{c2}\left(\frac{\lambda}{4\pi R}\right)^2 \text{ W} \tag{3}$$

where P_r the receiving power, in watts, P_d the receiving power density, in W/m^2, P_t the transmitter power, in watts; p_e the effective radiated power, in watts, g_{a1} the transmitting antenna gain (numeric), g_{c1} the transmitting line loss (numeric), g_{a2} the receiving antenna gain (numeric), g_{c2} the receiving line loss (numeric); R the range between two antennas, in meters; and finally λ, the wavelength, in meter.

The field intensity at a distance of R m from the transmitting antenna may be computed from the transmitter power. From Figure 1, the power density at the point of R m from the transmitting antenna is given by:

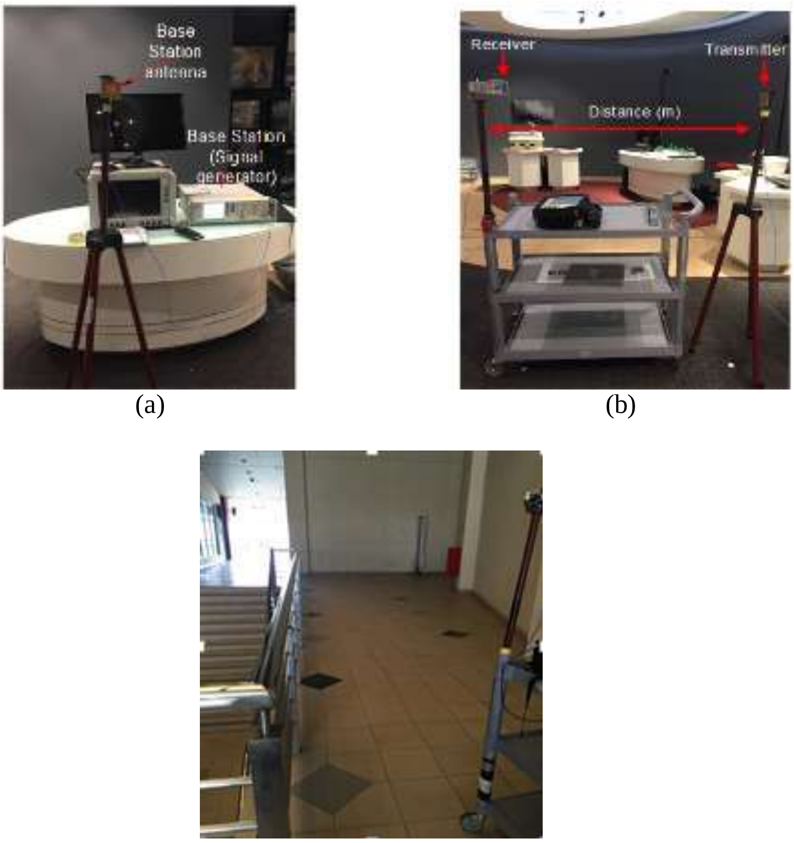
$$P_d = \frac{P_t g_{c1} g_{a1}}{4\pi R^2} \text{ W/m}^2 \tag{4}$$

From Figure 1, the power density at the receiving antenna is equal to the receiver power divided by the antenna gain, the cable loss, and the antenna aperture [21-23]. That is

$$P_d = (4\pi P_r)/(\lambda^2 g_{a2 g_{c2}}) \tag{5}$$

4. METHODOLOGY

In this work, the experiment has been set up to measure power density for 5G antenna operating at 28 GHz which can be used for the indoor base stations. The setup is made of the signal generator and the designed and fabricated antennas serving as the base station and the horn antenna and spectrum analyzer serving as the receiver. The transmitted signal was measured in an indoor environment and hallway as shown in Figure 2. In this experiment, the four antennas: single, 2x2, 4x4 and 8x8 array for 28 GHz has been measured. The antenna is connected to the signal generator and the value of power transmitted is 25 dBm. Then, the horn antenna is put at the receiver and connected to the spectrum network analyzer to get the value of power signal strength in dBm. All of the antennas have been measured and the value of the signal strength was obtained. The experiment has been done at Innovation Centre 5G (IC5G) at UTM Kuala Lumpur, the location is inside the IC5G and outside in hallway of IC5G. Then we compare the result of power density from both locations.



(a) (b)

(c)

Figure 2. (a) Base station setup (b) Indoor environment and (c) Hallway environment

The graph of the power density versus distance was plotted. In the graph below, the comparison of indoor and hallway for each frequency has been presented. The cable loss value has been measured for both frequency at the transmitter and receiver. The design of the microstrip antenna is shown in Figure 3. Parameters for antenna at 28 GHz

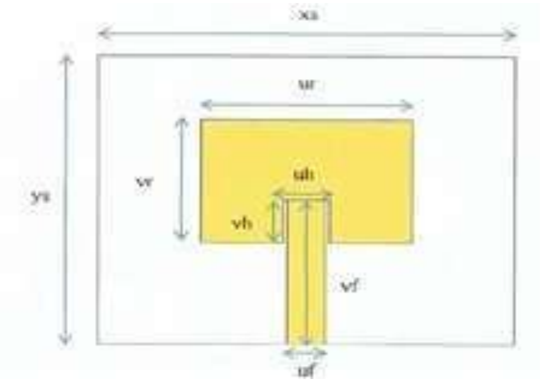


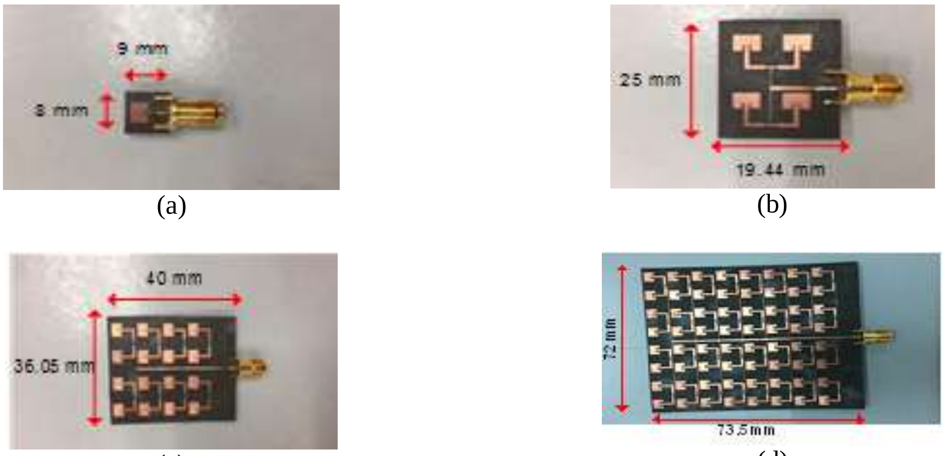
Figure 3. Dimension of microstrip antenna for 28 GHz

Table 1. Parameters for antenna at 28 GHz

Name	Parameter	Value (mm)
Width of substrate	xs	9
Length of substrate	ys	8
Thickness of substrate	zs	0.254
Length of radiating lement	ur	4.56
Width of radiating element	vr	3.43
Thickness of copper	zc	0.017
Width of hole	uh	1
Length of hole	vh	1.2
Width of feeder	uf	0.8
Length of feeder	vf	4

5. RESULTS AN DISCUSSION

In this part, the designed and fabricated that has been done using CST simulator, for the single, 2x2, 4x4 and 8x8 array at 28 GHz and the power density measured are presented in this section. The dimension of the antennas is shown in Figure 4 and the antenna gain is shown in Table 2.



(a) (b)

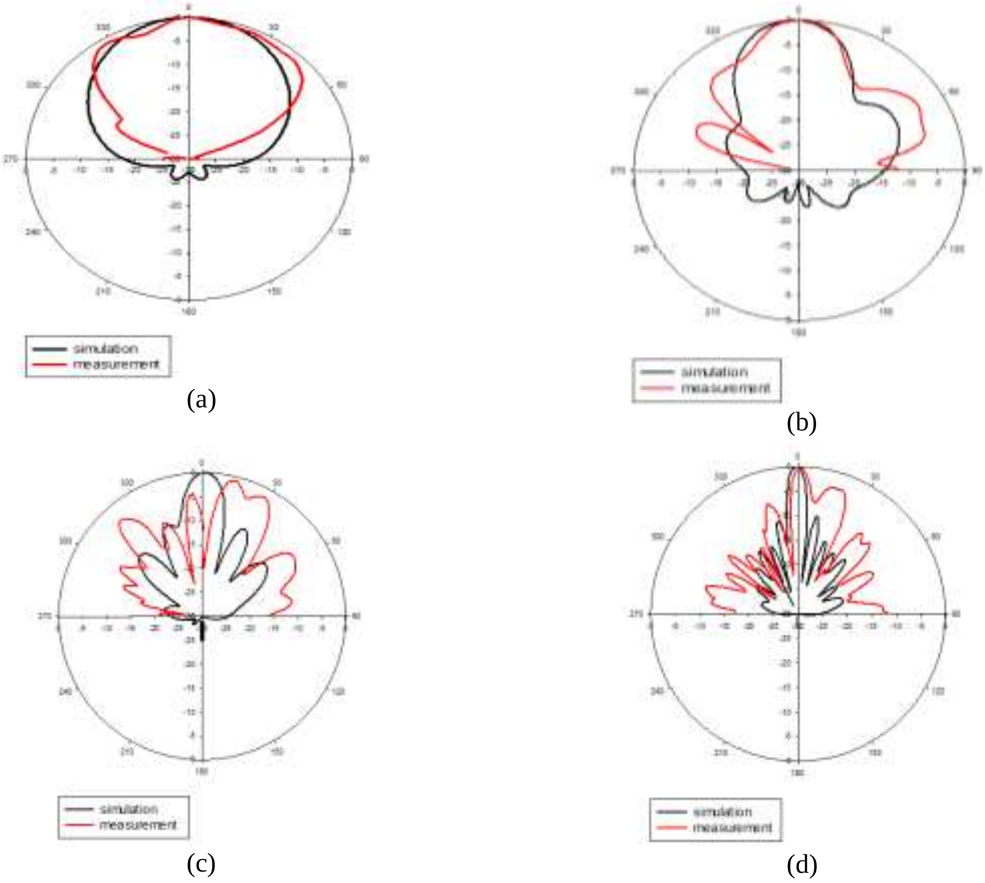
(c) (d)

Figure 4. Fabricated antenna (a) single, (b) 2x2 array, (c) 4x4 array, (d) 8x8 array at 28 GHz

Table 2. Gain value for all antenna

Antenna (28 GHz)	Gain Value (simulation) dBi	Gain Value (measurement) dBi
Single	7.75	7.07
Array 2x2	11.27	10.52
Array 4x4	17.75	16.23
Array 8x8	23.80	23.72

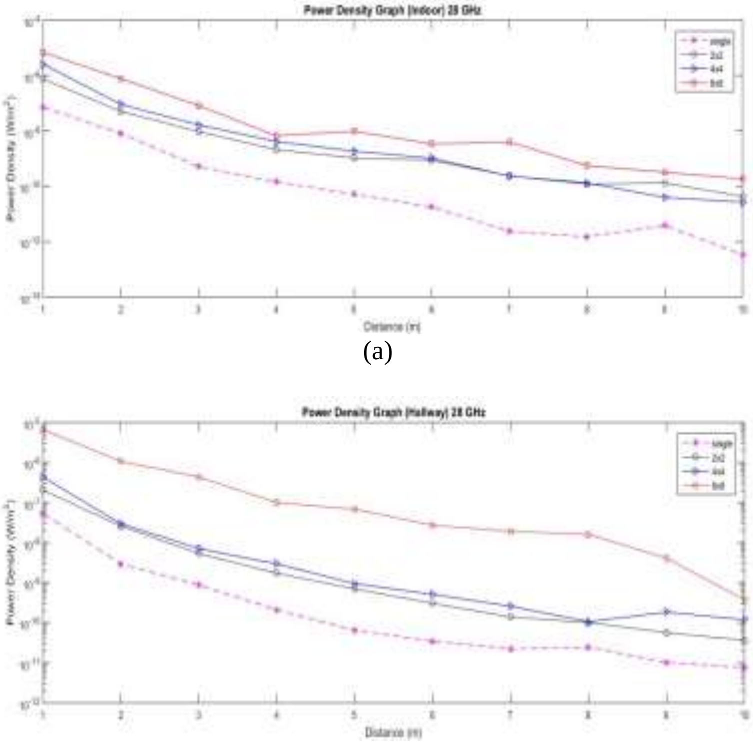
The result in Table 2 shows a corresponding increase in the antenna gain as the number of array elements increases. Figure 5 shows the radiation pattern for each of antenna by comparing it with simulation versus measurement. The result in Figure 6 shows the relationship of the power density versus the distance of the signal measured at the receiver. Figure 6(a) shows the measured power density at indoor location while Figure 6(b) shows the result at the hallway location. The result shows that the power density is inversely proportional to the distance. The power density of the indoor shown in Figure 6(a) is slightly higher compared to the hallway for all the antennas measured. This is as a result of the confined environment and the presence of obstacles such as the wall resulting to higher emission of the electromagnetic field. In addition, higher power density is obtained from the 8x8 antenna array compared to the 4x4, 2x2 and single antenna both in the indoor and hallway environment. This is because large array of antennas produces directional beams with higher antenna gain [24]. From the theory, the value of power density is based on the number of array and value of frequency [25-27]. Most importantly, the power density values obtained from the measurement are less than the ICNIRP compliance values which are 10 W/m^2 and 50 W/m^2 for public and occupational values, respectively at distance from 1 m and above. Additionally, Table 2 above shows the gain value comparison of simulation and measurement for all antenna at 28 GHz.



(a) (b)

(c) (d)

Figure 5. (a) Single antenna (h) plane, (b) array 2x2 (h plane), (c) array 4x4 (h plane), (d) array 8x8 (h plane)



(a)

(b)

Figure 6. Power density graph at 28 GHz, (a) indoor and (b) hallway

6. CONCLUSION

In this paper, the power density for the 5G frequency band at 28 GHz has been studied for an indoor environment. The measured distance considered is 1 – 10 meters for different array of microstrip patch antennas. In the exposure conditions examined in this paper, power density values well below the safety levels established by the most recognized international organizations have been found. From these results, it appears that exposure to the field radiated by 5G antennas cannot represent a risk for human health from the thermal point-of-view.

ACKNOWLEDGEMENTS

The authors would like to express utmost gratitude to the ministry of higher education (MOHE) in Malaysia and Universiti Teknologi Malaysia (UTM) for providing the financial support for this research through the FRGS grant (R.J130000.7823.4F965). The grant is managed by Research Management Centre (RMC) at UTM.

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