

# Highly efficient microstrip patch antenna for wireless gigabit alliance applications

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## ABSTRACT

A wireless gigabit alliance (WiGig) is widely known for higher bandwidth which operates at 60GHz unlicensed spectrum for super-fast data speed over short distances for millimeter-wave band application. This study offers an efficient, compact microstrip patch antenna for WiGig with a lesser return loss -50.45 dB (60 GHz). The gain and directivity of the proposed antenna are 13.01 dB and 13.42 dBi. It provides higher efficiency of around 91%. The proposed antenna also covers another mm-wave band that is at 95 GHz. The U.S. military uses electromagnetic radiation of 95 GHz as a non-lethal weapon. So, the anticipated antenna can be used for a miniaturized active denial system. The proposed antenna has a good gain, directivity, and efficiency for the multigigabits/s data rate. The aforesaid properties imply that it can be used for wireless personal area networks (WPAN) and wireless local area network (WLAN) and fifth-generation (5G) applications too.

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## 1. INTRODUCTION

One of the most promising aspects of the field of research is microstrip patch antenna (MPA). Since the 1970s, the microstrip patch antenna has been more prominent. Its characteristics such as lightweight, low size and cost, the capability for hand devices. In the paper, Sharma and Goyal [1] are the primary cause of its quick improvements. In future communication networks, we need an uninterrupted service for voice, video, and data. A large traffic volume requires extended bandwidth, which can be availed through higher frequencies such as an millimeter-wave [2]. Due to its better potential for achieving the tremendous spectral efficiency expected for wireless communication, millimeter-wave wireless communication has developed as a significant technology in fifth-generation (5G) cellular wireless systems [3]–[6].

The 60 GHz band (57-66) can be used in wireless services to ensure high-speed data transmission [7]. The IEEE 802.11ad standard is widely used for long-distance communications. One standard chose 60 GHz as its operating frequency. This system can transmit multigigabits/s. Due to the high path loss at 60 GHz, it requires a high antenna gain. More gain will cover more ground [8]. The 60 GHz band is expected to be the new era of wireless communication, replacing wired networks for better virtual reality, high file transfer, telemedicine, HD video streaming, and gaming experiences. IEEE 802.15.3c [9] and IEEE 802.15.3c [8] are other 60 GHz wireless local area network (WLAN) and wireless personal area networks

(WPAN) standards. millimeter-wave communication uses a horn antenna. It's also big, heavy, and expensive. It requires a lot of power and has other disadvantages [10]. Antenna miniaturization is now a major research focus. Because of this, the patch antenna is used for printed circuit boards (PCBs) due to its low cost, small size and high efficiency [11], [12].

Thakur *et al.* [2], [13]–[15] reviewed for 60 GHz microstrip patch antennas. In the paper, Thakur *et al.* [14] includes a 3.43 mm×3.83 mm microstrip patch antenna. The antenna is designed for future wireless communication at 60 GHz with a -25 dB return loss. The dielectric constant of the substrate is 2.2. In this case, 0.0005. The substrate material has a thermal conductivity of 0.22. A low bandwidth of 643 MHz in 60 GHz, and a gain of 6.75 dB. The the paper, Rabbani and H. G. Shiraz [2] is designed for 60 GHz gain and bandwidth. They get a -40 dB return loss. The antenna is proposed with R.T./duroid 5880 and a loss tangent of 0.0009. This antenna's patch sides are carved with symmetrical rectangular slits. It's two broad patch attaches fed in sequence. It has a 10 dB gain and 2 GHz bandwidth. Rectangular patch with photonic bandgap crystal substrate [16]. They used a photonic bandgap structure to improve radiation efficiency and bandwidth. Their return loss is -25 dB at 58.5 GHz. 4.9 GHz more bandwidth. The antenna is omnidirectional and 9.1 dBi directivity. In the paper, Abdelfatah [15] shows a patch antenna with a cavity resonator. The antenna is designed for 5G applications and has a 12 GHz bandwidth, which is very high. Its gain is 8.91, but its loss is higher. The antenna measures 4×2.7 mm<sup>2</sup> and operates at 60 GHz. In every aspect of antenna design, return loss is critical. The -21 dB rate of return loss is the antenna's only flaw.

Non-lethal weapons are a new technology that can protect people or military personnel. Non-lethal weapons include tear gas, hot water, pepper, electroshock, chemical reagents, and electroshock. Another method uses 95 GHz electromagnetic radiation, which can harm the skin. It was used as an active denial service in the US armed forces. It can be used as a non-lethal tool against physical harassment, mob control, jail check, and shelter control [16], [17]. Several of these issues and obstacles are carefully considered in the proposed rectangle patch antenna. First, we created a simplified rectangular MPA model. Second, we ran several simulations and analyses on the circuit before assessing and finishing our work. Then we compared the impact to other works. The paper ends with a short conclusion after comparing.

## 2. ANTENNA DESIGN

This WiGig antenna is specially designed for a 60 GHz frequency band; it constitutes a loss of low PCB RT/duroid5880, also  $\epsilon_r = 2.2$ . The loss of tangent ( $\tan \delta$ ) is 0.0009. The shape and dimensions parameters of the proposed antenna are illustrated in Figure 1. Two symmetrical parallel rectangular patches join with a metal cladding strip with  $L_{t2}$  and width  $W_{t2}$ . This patch is carved in the center with the length is "L," and the width is denoted by "W." This patch antenna design can be compared to a series fed with two extrawide patch antennas. This antenna has been constructed on substrate thickness (h) of 0.127 mm for a 60 GHz band.

Initially, the size enhancement approach is used to determine these sorts of antenna dimensions. One of the antenna's higher-order transverse electromagnetic (E.M) modes is used to expel it. The width W and length L of an extended patch antenna is closely matched with the fundamental mode, and the properties may be expressed as [18].

$$W = \frac{(2N+1)}{\sqrt{(\epsilon_r+1)/2}} \times \left(\frac{\lambda_0}{2}\right) \quad (1)$$

$$L = \frac{(2N+1)}{\sqrt{\epsilon_{eff}}} \times \left(\frac{\lambda}{2}\right) - 2\Delta L \quad (2)$$

Here,

N (non-negative integer) = 1

$\lambda_0$  = operational wavelength

$\epsilon_r$  = relative dielectric constants

The following formulas are denoted the patch length extension,  $\Delta L$  due to the effect of the fringing field-the effective dielectric constants  $\epsilon_{eff}$ .

$$\Delta L = 0.412h \frac{(\epsilon_{eff}+0.3)(0.264+W/h)}{(\epsilon_{eff}-0.258)(0.8+W/h)} \quad (3)$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \left(\frac{\epsilon_r-1}{2}\right)\left(1 + 12 \frac{h}{W}\right)^{-\frac{1}{2}} \quad (4)$$

Both are the input impedance  $Z_{in}$  [19], and the transmission line length  $L_T$  [20]. The antenna mentioned above is utilized to feed the antenna and provide impedance transformation. The recommended antenna is created using the specifications stated in Table 1, and its geometrical view is depicted in Figure 1.

The antenna is developed with a substrate thickness of  $h=0.127$  where,  $W_{t2} = W_{t1}/2$  and  $L_{t2} = L_{t1}/2$  at a frequency of 60 GHz to analyze the trade-off between the cumulative antenna, gain, and side lob levels in the far-field radiation pattern's vertical plane ( $\phi = 90^\circ$ ). The ground length, 'Correspondingly, ' $L_g$ ' and width ' $W_g$ ' are initially set to  $L+6h$  for  $L_g$  and  $W+6h$  for  $W_g$ . Using the final suggested antenna dimensions is adjusted via the optimization process.

Table 1. Diameters of 60 GHz MPA antenna (in mm)

| Parameter                | Value (mm)       |
|--------------------------|------------------|
| Substrate                | R.T./Duroid 5880 |
| $\epsilon_r$             | 2.2              |
| Patch width, W           | 5.59             |
| Patch length, L          | 4.49             |
| Patch height, t          | 0.035            |
| Substrate width, $W_g$   | 6.300            |
| Substrate length, $L_g$  | 5.202            |
| Substrate height, h      | 0.128            |
| Feedline width, $W_{T1}$ | 0.615            |
| Feedline length, $L_T$   | 2.475            |
| $W_{T2}$                 | 0.2975           |
| $L_T/2$                  | 1.45             |

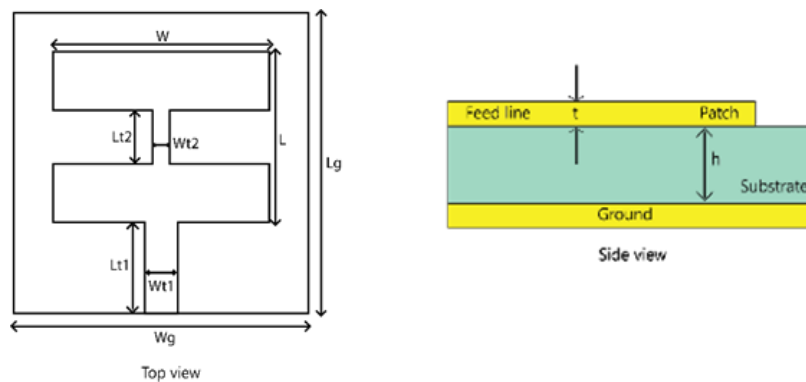


Figure 1. Proposed microstrip patch antenna

### 3. RESULTS AND DISCUSSION

A CST microwave studio program is used to assess parameters for antenna characteristics such as reflection coefficient, VSWR, gain, directivity, surface current distribution, power, and efficiency. The first findings for all of the parameters listed in Table 1 do not meet the benchmark. The following results are simulated, and the best performance is displayed after optimization.

#### 3.1. Return loss

The  $S(1, 1)$  is defined as the return loss of the antenna when  $S(1,1)$  is 0 dB, then much of the power is reflected. So, it is crucial to design an antenna for better performance less than -10 dB ( $S(1,1)$ ). Then the antenna radiation will propagate perfectly. Figure 2 shows that the proposed antenna resonates at 60 GHz and 95 GHz with the return loss value of 50.45 dB and 20.60 dB, respectively.

#### 3.2. Voltage standing wave ratio

The relationship between highest to lowest voltage ratio is considered as voltage standing wave ratio shortly VSWR on a lossless line. It values from range 1 to infinity. A VSWR of less than two is deemed to be appropriate for the majority of antenna applications. Figure 3 shows the results of the vswr. The proposed antenna fulfilled the condition described above and shows the VSWR is 1.00, 1.2 at 60 GHz and 95 GHz, respectively.

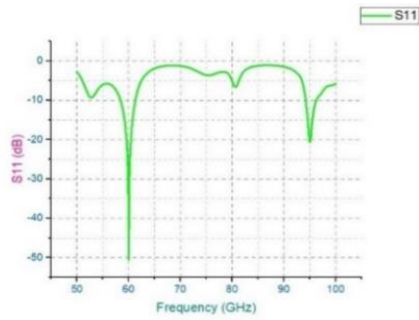


Figure 2. Return loss

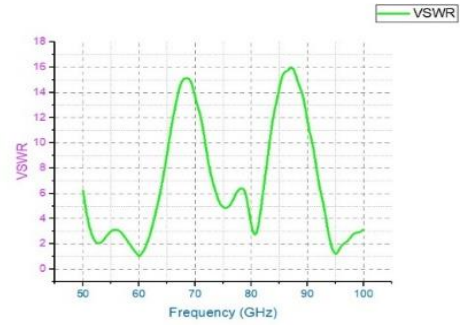


Figure 3. VSWR

**3.3. Surface current**

The distribution of surface power in Figure 4 is illustrated at Figure 4(a) for 60 GHz and Figure 4(b) for 95 GHz. It can be observed that the feeding line distributes the current so that the patch element receives a fair part of the current. Also implying that the patch element contributes to the antenna’s radiation.

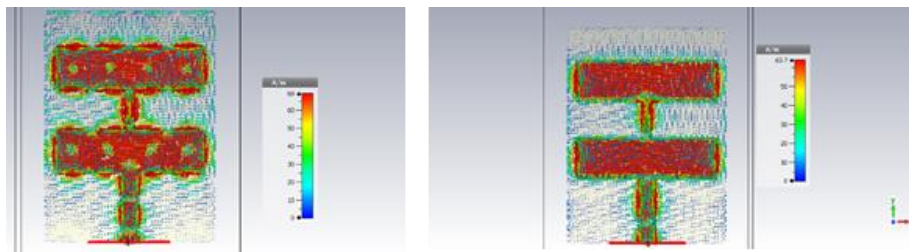


Figure 4. Surface current distribution (a) at 60 GHz and (b) at 95 GHz

**3.4. Gain**

The most excellent efficacy with which the antenna can radiate the power given to it by the transmitter towards a target is measured by antenna gain. Antennas gain in a particular direction is defined as the ratio of the intensity to the radiation intensity that can be achieved if the antenna's power is radiated isotopically. Antenna gain is usually measured in decibels (dB), which is a logarithmic scale. The proposed antenna shows an excellent gain at 60 GHz is 13.01 dB and 8.28 dB at 95 GHz. Figure 5 depicts the gain of two bands plotted by origin.

**3.5. Directivity**

Theoretically, the ratio of the radiation intensity in a specific direction from the antenna to the overall radiation intensity is measured as the antenna's directivity. The proposed antenna shows directivity is 13.42 dBi at 60 GHz and 9.23 dBi at 95 GHz. Figure 6 depicts the directivity of both bands at the same time.

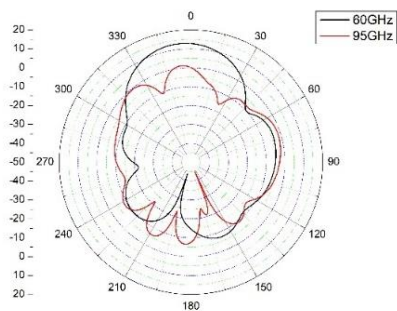


Figure 5. Gain at 60 GHz and 95 GHz

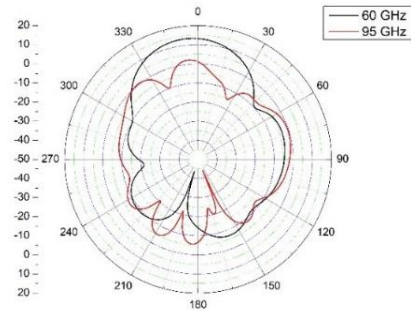


Figure 6. Directivity at 60 GHz and 95 GHz

**3.6. Power calculation**

The power calculation in Figure 7 for 60 GHz demonstrates the power accepting value is around 0.48 W, and the radiating power at 60 GHz is nearly 0.44 W, which provides a loss of 0.089W. Highly efficient power is radiating more than 91% in 60 GHz frequency. On the other side, the antenna is efficient enough is 95 GHz which includes the accepted power of 0.46 W, radiated power of 0.37, and the total loss of power is around 0.19 W. Figure 7(a) displays power distribution for 60 GHz and Figure 7(b) for 95 GHz respectively.

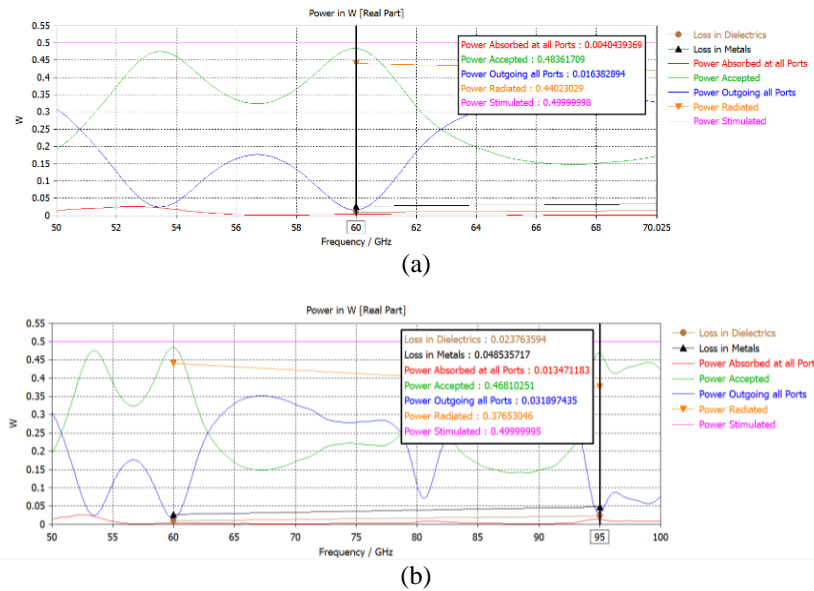


Figure 7. Power distribution (a) for 60 GHz & (b) for 95 GHz

**3.7. Efficiency**

We get 91% and 80.8% efficiency in the two bands described above as antenna radiation efficiency. This efficiency can be easily calculated by finding the ratio of accepted power and simulated power. On the other hand, the total efficiency at 60 GHz is 88%, and the total efficiency at 95 GHz is 75.3%. At Figure 8 all efficiencies are shown Figure 8(a) for 60 GHz and Figure 8(b) for 95 GHz respectively).

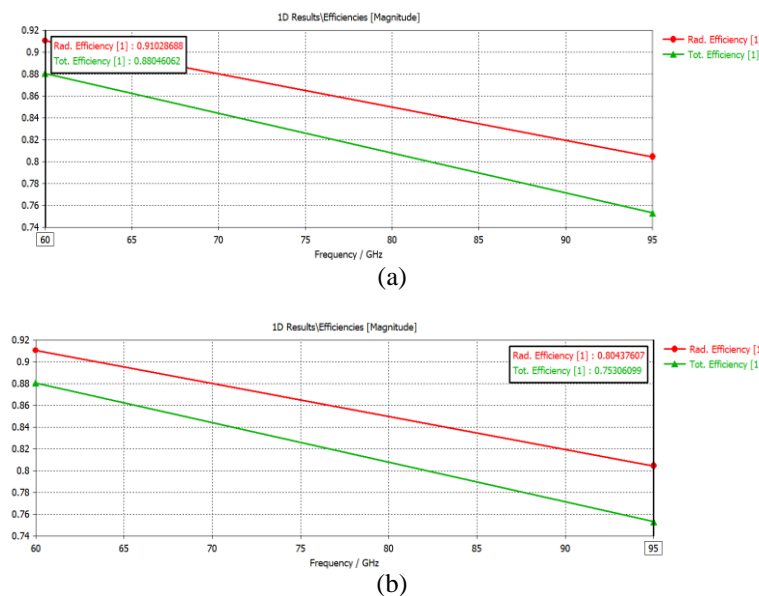


Figure 8. Radiation efficiency and total efficiency (a) at 60 GHz and (b) at 95 GHz

The simulated patterns of radiation for E- and H-planes are illustrated in Figure 9. (Figure 9(a) for 60 GHz & Figure 9(b) for 95 GHz respectively). As can be seen, in the E-plane and H-plane common patch antennas, the suggested antenna has an entirely consistent directional mode.

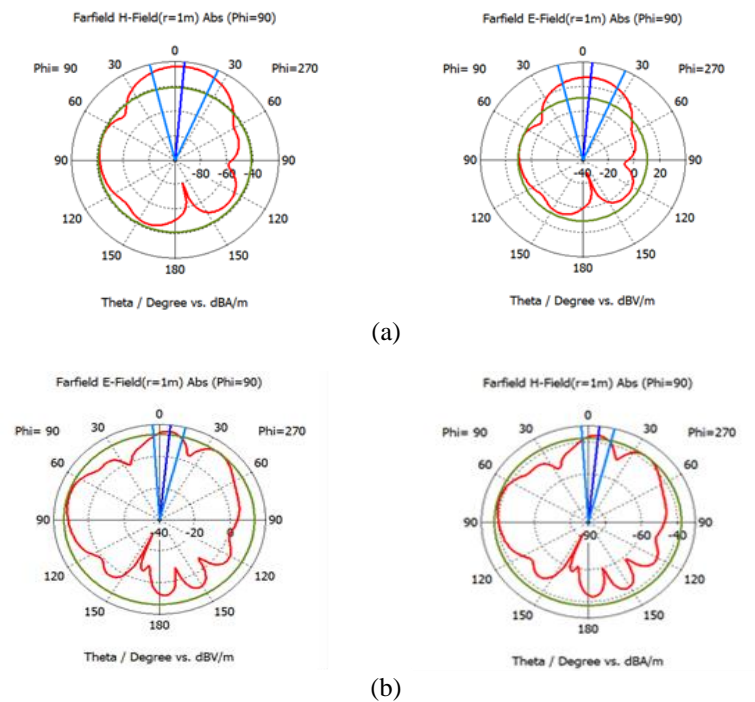


Figure 9. E & H plane for both frequencies (a) at 60 Ghz and (b) at 95 GHz

Finally, the suggested antenna has a low return loss, as well as a high gain and directivity. At 60 GHz, the efficiency is extremely impressive. The antenna's power plays an important role in maximizing efficiency. As a result, we discovered that the suggested antenna has a high efficiency. The port absorbs 97.95 percent of the input power and radiates 91 percent of it.

#### 4. COMPARATIVE ANALYSIS

The researchers have investigated the rectangular MPA designs for over a decade by testing its pattern at multiple frequencies. Testing on various applications such as compatible with 2G and 3G application on the basis at 2.1, 2.45, 3.1 GHz. We have studied and evaluated and then implemented our decision-making process, among other things. The different types of frequencies and fields are compared. In the design and simulation stages, we reach our model and its performance. Thus, following IEEE 802.11ad, IEEE 802.15.3c, and WLAN/WPAN applications, we can maximize the overall performance of our antenna at unlicensed wireless communication. We have obtained performance at the frequency of 60 GHz with the lesser return loss and better gain and directivity. The literature comparison concerning us is shown below in Table 2.

Table 2. Compared with similar work [15]

| Ref.             | Dimension (mm)     | $S_{11}$ (dB) | Center Frequency (GHz) | Gain (dB)    | Bandwidth | Directivity (dB) |
|------------------|--------------------|---------------|------------------------|--------------|-----------|------------------|
| [13]             | $3.43 \times 3.83$ | -25           | 60                     | 6.67         | 643 MHz   | -                |
| [2]              | $20 \times 22$     | -40           | 60                     | 10           | 2 GHz     | -                |
| [14]             | $2 \times 2.5$     | -25           | 58.5                   | -            | 4.9 GHz   | 9.1              |
| [15]             | $4 \times 2.7$     | -21           | 60                     | 8.91         | 12 GHz    | 9.16             |
| <b>This Work</b> | $5.2 \times 6.3$   | <b>-50.46</b> | 60                     | <b>13.01</b> | 2.9 GHz   | <b>13.42</b>     |

The papers listed above are in the simulated antenna chart. Our simulation achieved a lower return loss than the other comparable antenna in Table 2. Nobody could have done it. In the paper, Thakur *et al.*

[13] achieved 6.75 dB gain with a 643 MHz bandwidth and a  $3.43 \times 3.83$  mm antenna. The  $20 \times 22$  mm paper [2] has a -40 dB reflection coefficient and a 10 dB gain. The bandwidth is 2 GHz. In the paper, Tiwari *et al.* [14] focused on antenna downsizing to a -25 dB return loss at 4.9 GHz. The antenna is  $4 \times 2.7$  mm in size, with a -21 dB powerful reflection, 8.91 dB gain and 9.16 dBi directivity, and a 12 GHz bandwidth [15]. The proposed paper is unique in that it outperforms previous works on all parameters.

## 5. ANTENNAS IMPLEMENTATION FOR 60 GHz WiGig

As previously stated, the use of microstrip patch antennas at 60 GHz for WiGig applications is of current interest. Several studies on WiGig have been conducted recently. However, 60 GHz millimetre waves cannot penetrate walls. Using WiGig's beamforming, it can propagate through walls, ceilings, floors, and objects. In a square room with a diameter of 10 meters and a height of 3.5 meters, two antennas at a 45-degree angle can provide 100% coverage for point-to-point communications. The xz aircraft requires a 1.5-meter wireless service [21], [22]. A small feeding approach to the proposed antenna to create an antenna array can be helpful for various mm-wave and THz applications [23], [24]. The project may be used to intelligently pick joint transmissions that have a greater level of dependability than the others in the system [25]. Figure 10 depicts a graphic illustration of the process of configuring the antenna.

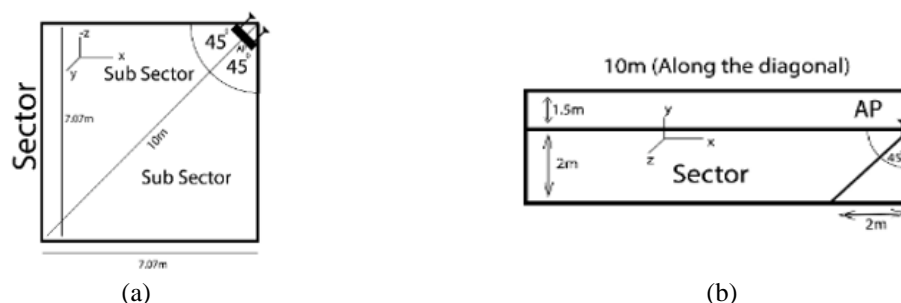


Figure 10. For full WiGig coverage in a room (a) top view and (b) side view

## 6. CONCLUSION

WiGig is now a low-power technology with massive bandwidth that claims to use five times less energy than Wi-Fi. It features "beamforming" technology to concentrate its radio beams for optimal performance, minimizing congestion and effectively sending the radio signal where it is needed. Necessarily for a multi-gigabit transmission rate, tiny MPA, has been suggested and developed for wireless communications. It is very lightweight, can implement any PCB for its compact size. Another aspect is that the substrate is based on a low dielectric constant. These characteristics are beneficial for the worldwide mobility of wireless communication equipment. The parametric analysis offers information on the impact of various dimensional factors. It explains how to construct and optimize a square rectangle microstrip patch antenna. By raising the height of the substrate, the bandwidth may be readily increased. IEEE instructs the 60 GHz WLAN/WPAN application is ready to use by fulfilling its standard level. A non-lethal weapon can be used for firing at a 95 GHz wave by using a high-power beam. In addition, the proposed antenna has a comparatively excellent gain.




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