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Abstract— This paper presents the design of a rectangular patch antenna array for 5G wireless communication using CST microwave studio. Rogers RT5880 LZ dielectric with properties of $h = 0.762\,\text{mm}$, $\varepsilon = 1.96$ and $\delta = 0.0025$ has been used as a substrate of the proposed design. The length of the single patch antenna is 3.0526 mm and width of the patch is 4.2352 mm. The distance between two antenna elements is 0.63λ. The side lobe level and half beam width of two element array are reduced as compare to a single element. The return loss of proposed design is less than $-10\,\text{dB}$. The single patch antenna is working in the range of 26.5 GHz to 28.8 GHz, having 8.2% impedance bandwidth and gain is 7.8 dB. For two element antenna array, the impedance bandwidth is increased up to 28.86% and also gain is increased.

1. INTRODUCTION

In Wireless communication, antennas playing an important role. Different antennas have been designed for different application i.e., for WLAN, PCS, 3G and for 4G [1–4]. The use of smart-phones and the speedy growth of data rate generating unexpected challenges for the wireless service providers that to overcome the total bandwidth scarcity, to deliver low latency with high-quality video and multimedia application for wireless devices [5]. In 5G cellular system is shifted higher frequency where it is easy to obtain the wideband. The centimeter or millimeter wave can provide very wide bandwidth as compared to 3G or 4G frequency bands. There are different bands are selected for 5G one of them is 28 GHz [8–11]. To move to theses millimeters waves band it will create new challenges in the design of antennas for the mobile device and base station. However many challenges lie ahead of using millimeter wave frequencies which include propagation loss shadowing, sensitivity to blockage, large scale attenuation of human bodies and materials and atmospheric absorption. To control these challenges, we need high gain high directional beamforming antennas for both mobile device and at base station should be deployed. The beamforming can be applied to overcome the path loss at millimeter wave frequencies [5–11].

The antenna array plays has an important role in long distance communication due to its high transmit and receive gain, spatial diversity, interference suppression, and angle of arrival estimation [5]. The microstrip antennas consist of four parts i.e., the ground, patch, substrate, and feeding part. The patch antenna can be categorized as a single resonant element or more than single antenna elements. The patch is very thin i.e., the thickness of the patch is very very small than free space wavelength, λ_o of the radiating metal strip or array of strips that is located on one side of the substrate. The thickness of substrate layer is in between 0.01 to 0.05 of the free space wavelength [2]. The purpose of the substrate is to separate the ground plane and the radiating patch. The insertion loss of the substrate should be low and the loss tangent should be less than 0.005. The advantage of the microstrip patch antennas is that it has a small size, low profile and lightweight conformable to the nonplanner and planner surfaces [1–3].

In this paper, we have proposed unit element and two element patch antenna array for 28 GHz operating frequency. The directivity of the antenna array is increased as compared to the unit element. The remaining paper can arrange as, the Section 2, address the analysis and design of single patch antenna, Section 3 address the simulated results of the single patch antenna and two patch antenna array while the last Section 4 address the conclusion.

2. ANALYSIS AND DESIGN

Usually, the length of the rectangular microstrip patch is in between lambda/3 and lambda/2 where lambda (λ_o) is the free space wavelength when is too small the antenna will become a microstrip line, not a radiator. The substrate thickness should be much smaller than λ_o [1,2]. Their relative permittivity normally in between 2 and 24 it has no unit. The fringing field is separated by $\lambda_o/2$ at the open end.

The radiation is produced due to the fringing field of two open ends. The radiation plane in two principle plane is given by [2]. For E-plane, when phi $= 0^\circ$ the radiation pattern can be found by using Eq. (1).

$$E = \hat{\theta} E_o \cos\left(\frac{\beta L}{2}\sin\theta\right) \tag{1}$$

And for H-plane i.e., phi equal to 90° then radiation pattern can be written as

$$W = \hat{\phi} E_o \sin c\left(\frac{\beta W}{2}\sin\theta\right)\cos\theta \tag{2}$$

There are many methods of feeding a microstrip antenna i.e., microstrip line, coaxial probe, and proximity coupling. The most commonly used method is a microstrip line. Because it is very simple to manufacture [1]. The feeding method for the proposed patch antenna is given in Figure 2. This method is widely used to design single and also for patch antenna array. The impedance of a patch by using Eq. (3) given by [2].

$$Z_L = 90\frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \tag{3}$$

where L represent the length of the patch and W represent the width of the patch antenna. A transition line is designed to match Z_L with 50-ohm line microstrip line. The impedance of the transition line is calculated by using Eq. (4)

$$Z_T = \sqrt{Z_L \times Z_0} \tag{4}$$

where Z_0 is the 50-ohm microstrip line and Z_L is the load impedance [1,2]. The width of transition is given by [7].

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{8h}{w_t} + \frac{w_t}{4h}\right) \tag{5}$$

Here h is the thickness of the substrate and 'w_t' is the width of the quarter wave transformer or transition line. The width of 50-ohm microstrip feed can be calculated by using Eq. (6).

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left(1.393 + \frac{W}{h} + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right)} \tag{6}$$

The length of the of transition line is quarter wavelength and is calculated by using Eq. (5).

$$l = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon_{reff}}} \tag{7}$$

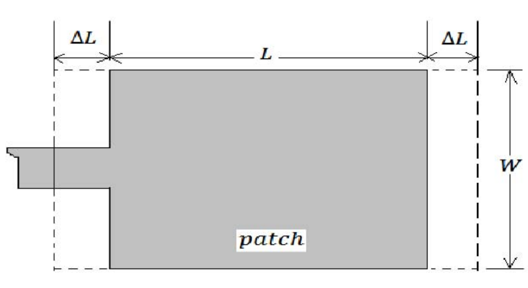


Figure 1: Single patch with extended effective length (delta L).

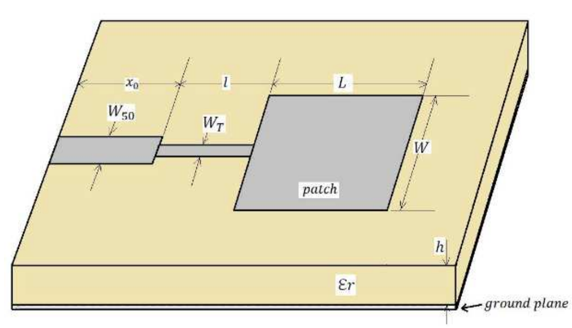


Figure 2: Design of proposed single patch.

The patch antenna looks like larger than its actual length because of the fringing effect. The increment in actual length is given by [2]

$$\nabla L = \frac{0.412d\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left[\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)\right]} \tag{8}$$

And also effective relative permittivity can be written as according to [1, 2]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W}}} \tag{9}$$

where W, represents the width of the patch and calculated by using following equation

$$W = \frac{1}{2f_r\sqrt{\varepsilon_o \mu_o}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{10}$$

The effective length (L_{eff},) of the patch antenna is given by [1, 2]

$$L_{eff} = L + 2\nabla L \tag{11}$$

The length L is determined as

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} - 2\nabla L \tag{12}$$

The ground part of the antenna is very important. Ideally, it is infinite like for monopole antennas. The radiation of microstrip antenna is generated due to the fringing field between the ground plane and patch. Generally, there is a $\lambda/4$ extension in the edge of the ground plane [1, 2].

3. NUMERICAL RESULTS

For multiple antenna elements i.e., for an antenna array, it is necessary to design a single patch antenna element [5–11]. Eq. (12) is used to find the length of the patch at 28 GHz which almost equal to 3.1535 mm, with using Roger substrate having thickness 0.762 mm and permittivity equal to 1.96. where the width of the radiating patch is 4.4035 mm Load impedance is calculated using Eq. (3) around about 196.59 Ohm.

A transition line is used to match the load with 50 Ohm input feed line. Eq. (4) is used to find the impedance of transition line having an electrical length equal to $\lambda/4$. The impedance of transition line is around about 99.14 ohm where for the width of transition line Eq. (5) is used which is almost equal to 0.3660 mm. the width of 50-ohm line is equal to 2.7380 mm. The simulated results S_{11} are shown in Figure 4(a). The patch is resonated from 26.5 GHz to 28.79 GHz. The far field gain is shown in Figure 4(b) at 28 GHz. The gain of the single patch is 7.86 dB and the impedance bandwidth is 8.28%.

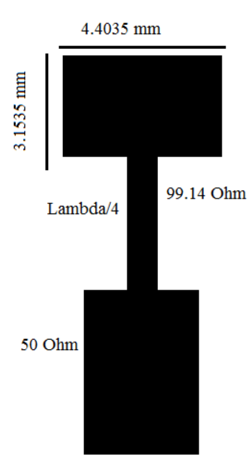
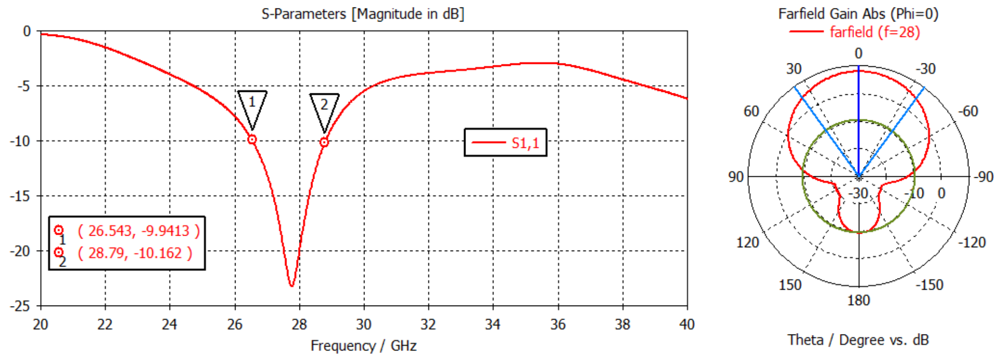


Figure 3: Dimension of single patch antenna.



(a) (b)

Figure 4: (a) Return loss (S_{11}) for single patch, (b) 7.8 dB Gain for single-element antenna array.

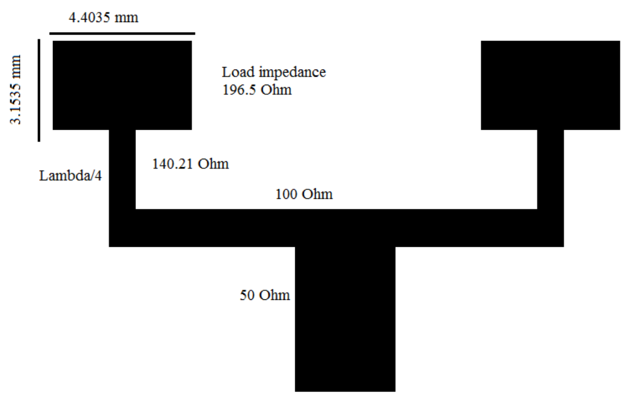
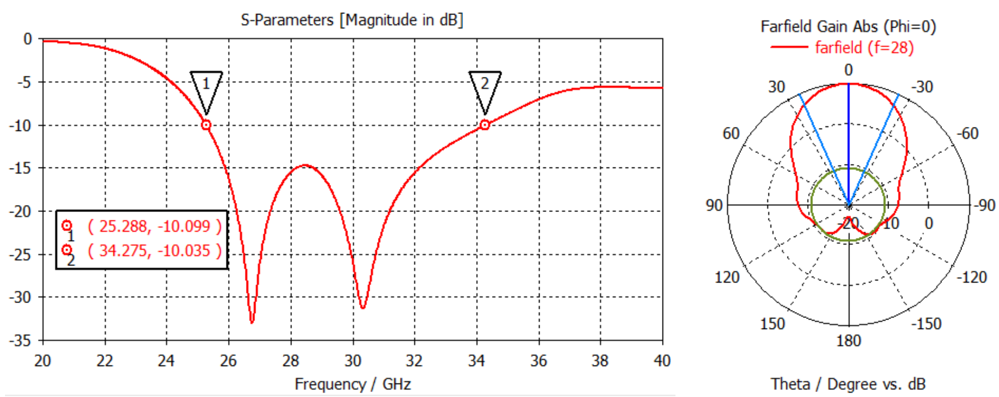


Figure 5: Design of two element antenna array.



(a) (b)

Figure 6: (a) Return loss (S_{11}) in dB for two elements, (b) 10.7 dB Gain for two-element antenna array.

Two patch antenna element's array is designed to improve the gain and impedance bandwidth. Two element antenna array is shown in Figure 5. The 50 Ohm feed line is matched with 100 Ohm line i.e, according to power divider, for the 50-ohm feedline the output microstrip line should have an impedance equal to 100 Ohm. The 196.59-ohm patch is matched with 100-ohm microstrip using transition line having an impedance equal to 140.21 ohms. The spacing between two elements is 0.63λ. The return loss is shown in Figure 6(a) which show that the impedance bandwidth is increased up to 28.86 %. Far field gain is shown in Figure 6(b) the gain is improved 7 dB to 10 dB.

4. CONCLUSION

A single rectangular patch antenna was designed for high frequency i.e., for 28 GHz. The size of the single patch is so small that has a narrow band and low directivity the impedance bandwidth and gain was 8.2% and 7.9 dB for a single patch the return loss (S_{11}) is less than −10 dB for 26.5 GHz to 28.8 GHz. To improve the directivity and bandwidth two element antenna array was designed that shows the matching from 25 GHz to 34 GHz i.e., the return loss was less than −10 dB and the impedance bandwidth was increased up to 28%. The gain is also improved from 7.8 dB to 10.7 dB.

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