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DESIGN OF SINGLE FEED DUAL-BAND MILLIMETER WAVE ANTENNA FOR FUTURE 5G WIRELESS APPLICATIONS

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ABSTRACT

State of the art communication system pave way for microstrip patch antennas to experience rapid development. Nowadays, patch antennas are becoming increasingly popular due to their light weight and low profile making them easy to fabricate and integrate into the feeding network. This paper presented a single feed dual-band band antenna for 5G application operating in the 28 and 38 GHz millimeter wave band with an improved efficiency. The antenna is designed and simulated on Computer Simulation Technology (CST) platform using FR-4 substrate with 0. 8 mm height, 4.67 dielectric constant and 0.002 loss tangent. The total size of the antenna is 8 × 8 mm^2, the rectangular radiator of the antenna is 3.4 × 3.4 mm^2 in size, where an inverted-L is introduced into the radiator to achieve dual-band capability, The antenna is fed through 50 Ω feed line probe of about 2.3 × 0.4 mm^2 in dimension. The results of the simulation shows that the antenna achieved wide bandwidth in the upper band (38 GHz) of about 3.54 GHz (35.56 GHz – 39.12 GHz) with over 6 dB gain and the lower band (28 GHz) produce a bandwidth of about 1430 MHz (27.27 GHz – 28.70 GHz) with 2.7 dB gain suitable for 5G applications.

Keywords: millimeter wave, 5G, CST, inverted-L slot, Wide bandwidth.

INTRODUCTION

Wireless communication system has been battling with spectrum allocation in the microwave frequency band due to its limited availability(Nosrati & Tavassolian, 2017). Additionally, the explosive growth of internet over the years with extremely high data rates, low latency and higher bandwidth have transformed the attention of researchers to look for further frequency bands that can be deployed in the future wireless communications technology(Muhammad, Yaro, & Alhassan, 2018; Nosrati & Tavassolian, 2017). The evolving fifth generation technology (5G) integrate the existing wireless interface with future one for higher frequency and spectrum efficiency. Ecosystem design and network system requirement for the auspicious 5G access technique are the leading challengers for the actual deployment of the emergent 5G technology between years 2020 to 2030(Ding & Janssen, 2018). Effort has been made by IEEE to support and handle explosive volume of data for wireless broadband application through IEEE 802.11ad and IEEE 802.15.3c standards. The former specifies the PHY and MAC layer specifications to support Multi-Gigabit wireless application at millimeter wave (mmWave) frequency while the latter works on PHY and MAC layer to support indoor pico-net or wireless personal area network (WPAN)(Aliakbari et al., 2017; Niu, Li, Jin, Su, & Vasilakos, 2015). 5G technology to exploit the use of mmWave band in order to achieve high data rates, and the abundant frequency band can handle the limitations of spectrum allocation in microwave band.(Agiwal, Roy, & Saxena, 2016). Shorter wavelengths in mmWave antennas, with minimum interference due to narrow beam width and nature of the signal is what qualifies it to attain high directivity and gain(Liu, Pfeiffer, Grzyb, & Gaucher, 2009; Rappaport, Heath Jr, Daniels, & Murdock, 2014; Yu & Kamarudin, 2016). A number of frequency bands have been standardized by the fifth generation partnership project for various applications and currently 28 GHz, 38 GHz and 73 GHz operating band have been explored for 5G networks. A patch antenna with dual-band or multiband capability to cover the aforementioned range is therefore required(Rappaport et al., 2013).

The ability of patch antennas to perform multitasking applications such as beam scanning, multiband operation, wide bandwidth, dual polarization, and feed line flexibility is what makes it suitable and favored over other designed approach(Yahya, 2011). Highly directional and reconfigurable antenna architecture can be deployed in outdoor environment to vanquish the effects of multipath and reduces signal to interference noise ratio (SINR)(Gampala & Reddy, 2016; Hur et al., 2013). Zhang et al (2017) proposed that circular antenna array tends to have higher gain and directivity making them more appropriate for mmWave communication due to larger amount space they occupied than other design architecture(Zhang, Ge, Li, Guizani, & Zhang, 2017). Furthermore, diversity techniques can significantly enhance system capacity as seen in polarization diversity where a single antenna with multiband capability can be deployed to create multiple polarization.

Researches on dual-band antenna for 5G mmWave applications are still in process and need much attention from researchers(Aliakbari, Abdipour, Mirzavand, Costanzo, & Mousavi, 2016; Elsheakh, 2017). In order to address the issue of single band design presented in open literature with narrower bandwidth, a single fed low profile dual-band mmWave antenna is presented for future 5G applications. The antenna covers 28 GHz and 38 GHz frequency band with an inverted L-slot functionality that is easy to fabricate. A nearly stable omnidirectional radiation pattern over the two bands of interest is achieved.

The remaining section of the paper is organized as follows: The methodology of the designed antenna is presented in Section II, Section III discussed results of the simulation and section IV concluded the paper.

METHODOLOGY

In this section, the methodology of the designed antenna is presented. The work considered rectangular Microstrip patch antenna as a frequently used shape in the design and construction of wideband antenna that operates in either microwave or mmWave bands. Fig. 1 presents the overall structure of the proposed dual-band antenna operating at 28 GHz and 38 GHz frequency bands for 5G mobile applications, the total size of the antenna is 8 × 8 mm^2 which is compact enough to be used in the future slim, slick and compact devices. The rectangular radiator is located in the front view of the antenna of about 3.4 × 3.4 mm^2 size, an inverted-L is introduced in the radiator to achieve dual-band capability. The antenna is fed through 50 Ω feed line probe of about 1.5 × 0.4 mm^2 in dimension. The lower side of the feedline is 0.8 × 0.9 mm^2 rectangular slot transmission line that matches the impedance of the line to the radiating patch. The ground of the antenna is located at the backside with the same size to that of the overall antenna. The antenna is designed on flame-retardant type 4 (FR-4) substrate with 0. 8 mm height, 4.67 dielectric constant and 0.002 loss tangent, FR-4 is selected due to its light weight and low cost.

The patch radiator is designed using closed-form equations for the fundamental mode in the following steps:

i. The width (Wp) of the patch is calculated using (1).

$$W_p = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

Where: $\varepsilon_r = 4.67$ is the relative permittivity of the dielectric substrate, c = speed of light in vacuum, and f_o= 28 GHz is the resonant frequency of the antenna.

ii. The length (Lp) of the patch is determined using (2).

$$L_p = L_{eff} - 2\Delta L \qquad (2)$$

Where: L_{eff} and ΔL are the effective length of the patch and the path length extension which are determined using (3) and (4) respectively.

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \qquad (3)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W_p}{h}+0.8\right)} \qquad (4)$$

Where: ε_{eff} is the effective relative permittivity of the dielectric substrate and is determined using (5).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+\frac{12h}{W_p}}}\right] \qquad (5)$$

h = height of the dielectric substrate.

The length and width of the ground plane are calculated using the following equations (Kumar & Kumar, 2018).

$$L_g = 6h + L_p \qquad (6)$$

$$W_g = 6h + W_p \qquad (7)$$

Similarly, the length and width of the substrate are of equal size to that of ground plane (i.e. $L_g = L_S$ and $W_g = W_S$).

The antenna is fed using quarter-wavelength transmission line, there by matching the input impedance to the radiating patch of size W_{f1} with 50 Ω transmission line along W_f. The parameter of the feedline can be tune by varying the width of the quarter-wavelength strip. The larger is the strip, the lower the characteristics impedance of the 50 Ω transmission line section (Alisher & Fazilbek, 2016; Balanis, 2012; Pozar, 2009).

The inverted-L slot of size 2.67 × 0.2 mm^2 is loaded in to the radiator to achieve the upper 38 GHz frequency band, and the length of the slot is chosen from the concept of slot antenna, 2.67 mm length correspond to about λ/4 equivalent value of the upper frequency band.

The model equation provide the basic parameters of the designed antenna which are then transformed into the Computer Simulation Technology (CST) software.

Table 2. Dimension of the Proposed Antenna

Parameter	*Ls*	*Lp*	*L1*	*Lp*	*Lf1*	*Ws*	*Wp*
Dimension (mm)	8	3.4	2.27	3.4	1.5	8	3.4
Parameter	*h*	*W*	*Lf*	*Wf*	*Wf1*	*W1*	*W2*
Dimension (mm)	0.8	2.4	0.8	0.9	0.4	0.6	0.2

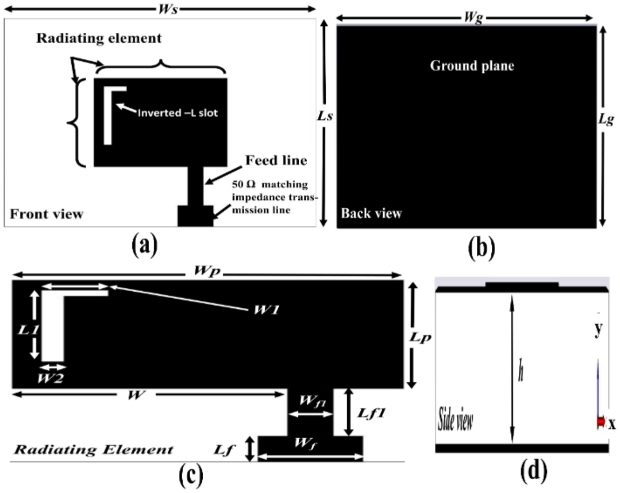

Figure 1: Geometry of the proposed Antenna (a) Front view (b) Back view (Ground plane) (c) Radiating element and (d) Side view.

SIMULATION RESULTS AND DISCUSSION

The propose designed is modeled and simulated with CST studio a Microwave simulation software programs that allows each and every layer of the designed antenna to be assigned with equivalent physical and electrical properties. The reflection coefficient magnitude $|S_{11}|$ is one basic antenna parameters that is use more often in antenna design analysis. The $|S_{11}|$ parameter highlight the amount of energy reflected from the antenna input with respect to the operating frequency. Return loss (RL) and $|S_{11}|$ are analogous to each other, and a -10 dB RL (corresponding to about 90% of the antenna energy that is successfully been transmitted or received) is used for practical wireless communication devices (Balanis, 2012). The proposed antenna covers 27.27 GHz – 28.70 GHz in the lower band and 35.56 GHz – 39.12 GHz in the upper band as depicted in Figure. 2 is considered to be favorable for wireless communication application. The interaction of reflected waves with forward waves give rise to standing wave patterns. Lots of electrical energy cannot properly be transmitted for an antenna with mismatch impedance feed line. For maximum energy transfer from the feed line to the antenna and vice versa (i.e. transmitter or receiver) the Voltage Standing Wave Ratio (VSWR) of the given antenna must be at least in the ratio of 2:1 or less. This is to help understand the amount of power forwarded/received successfully to that been reflected due to mismatch. Figure. 3 shows the results of the VSWR which is analogous to the return loss and a good VSWR of about 1.2:1 and 1.8:1 at the upper and lower band is realized respectively

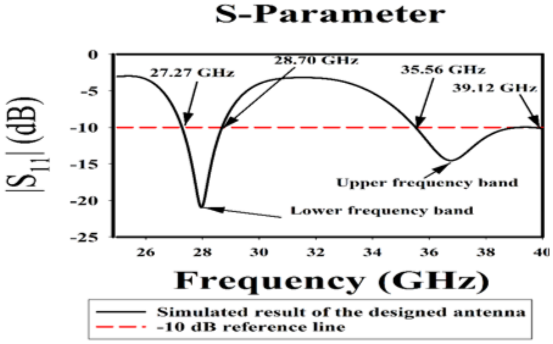

Figure 2: Reflection coefficient magnitude against frequency of the proposed antenna.

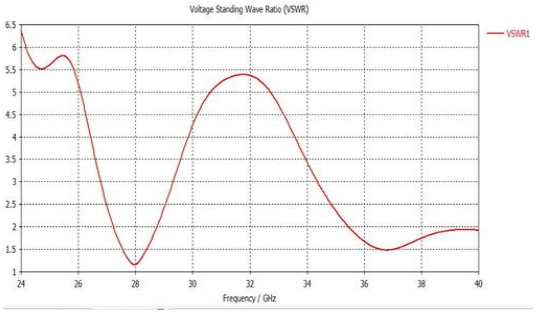

Figure 3: VSWR curve of the proposed antenna

Figure. 4 and 5 provide the radiation and gain of the designed antenna at 28 GHz and 38 GHz respectively. Patch antennas are known to radiate their energy normal to their patch surface and it is important to analyze elevation pattern of the maximum realized gain and directivity for $\Phi = 0^o$ and $\Phi = 90^o$ degrees. In the lower frequency the realized gain is about 2.7 dB and that of the upper band is about 6.43 dB and directivity of the antenna at $\Phi = 0^o$ and $\Phi = 90^o$. The realized wide bandwidth and high gain achieved by the designed antenna shows that antenna is suitable for 5G mobile applications.

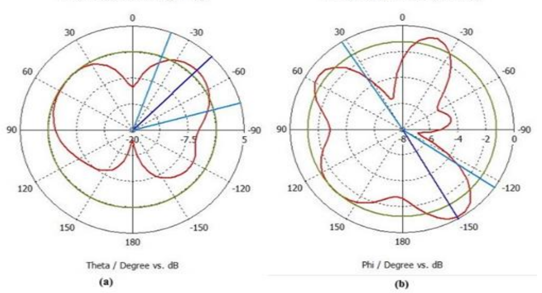

Figure 4: Simulated 2D radiation pattern at 28 GHz (a) $\Phi = 90^o$ (b) $\Phi = 0^o$

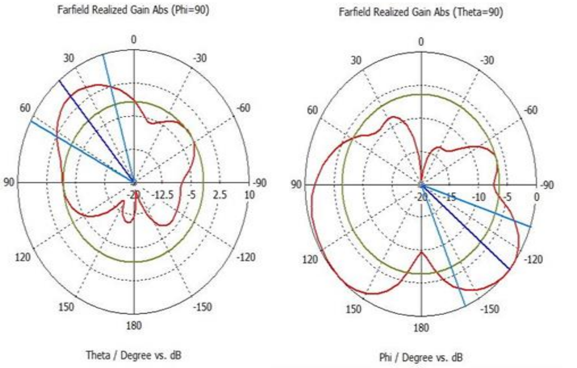

Figure 5: Simulated 2D radiation pattern at 38 GHz (a) $\Phi = 90^o$ (b) $\Phi = 0^o$

Conclusion

A single feed dual-band antenna operating at 28 GHz and 38 GHz as upper and lower operating frequencies band respectively is presented for 5G mobile application. The total size of the antenna is 8 × 8 mm^2 portable enough for modern wireless device application. To enhance the bandwidth of the upper frequency band, an inverted-L slot is inserted into radiating patch element. Wide operation bandwidth is realized from the designed antenna at about 1.43 GHz ranging from (27.27 GHz – 28.70 GHz), and 3.54 GHz (35.56 GHz – 39.12 GHz) in the upper and lower frequency band respectively. The realized bandwidth is suitable and deployable in bandwidth less constraint environment. Hence, the proposed designed antenna tend to be more efficient in terms of high gain and bandwidth, as compare to the one's presented in the open literature. The gain realized in the lower frequency band is about 2.7 dB and that of the upper frequency band is above 6 dB.

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