Bulletin of Electrical Engineering and Informatics
Vol. 8, No. 3, September 2019, pp. 1004~1013
ISSN: 2302-9285, DOI: 10.11591/eei.v8i3.1519

Multiband antenna using stacked series array for Ka-Band application

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Article Info

Article history:

Received Mar 10, 2019
Revised May 12, 2019
Accepted May 28, 2019

Keywords:

Dual-layer substrate
Multiband antenna
Stack series array

ABSTRACT

In this paper, a multiband stack series array antenna is designed in order to attain solutions for the future 28 GHz Ka-band application. Double layer substrate Technology is utilized to accomplish multiple resonant frequencies with higher data transfer capacities due to high bandwidth. The designed antenna is dependent on twofold layer consisting patches and resonators in different layers stacked together. The designed multiband antennas can resonate at single band of (28 GHz), dual band of (28 and 30 GHz) and triple band of (24.18, 26 and 28.453). The results achieved in the simulation are later fabricated and tested. The test result illustrates that the antennas have wide bandwidth, high gain and even higher efficiencies. All the proposed antenna configurations have demonstrated a decent possibility for 5G millimeter wave (mmwave) application.

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1. INTRODUCTION

The upcoming wireless technology of fifth generation (5G) will adapt up to the expanding need for reliability and speedy network system. 5G is relied upon to convey improved speeds and coverage than the present fourth generation and long-term evolution (4G & LTE) facilities. Cell phones and other different gadgets that are being utilized every day have achieved a specific aspect where the applications they run produce more information than any time in recent memory. To maintain this measure of information effortlessly the wireless network that kepps the devices connected with each other also must adjust to keep up with the pace. That is the reason why telecommunication companies are competing to switch to the fifth generation of wireless network technology.

However, there are abundance of challenges to look forward to achieve 5G networks. Out of them one of the main concern is Mm wave. Mm wave has large bandwidth which fulfills the basic obligation for 5G networks, so, that is the reason why Mm wave is acknowledged to be one of the feasible candidate for 5G networks [antenna 4]. A huge expansion has occurred in the case of mm wave frequency spectrum, to be more precise at 28 GHz and beyond which is basically unnoticed until recently. On October 22nd 2015, new rules have been proposed by Federal Communications Commission (FCC 15138) for wireless broadband frequencies of 28 GHz, 37 GHz, 39 GHz and 64-71 GHz bands [1]. These frequencies have been targeted for 5G applications by different researchers.

Mm-Wave frequencies have some benefits such as better resolution and higher data rates when matched with applications that require lower frequency spectrum, both of these are necessary for systems which possess better proficiencies and over-all higher levels of functionality [2]. Moreover, designing a mmWave antenna which is promising enough to satisfy the 5G requirement is another challenge all-together for the researchers. To overcome the challenges of 5G researchers are suggesting different types of antennas. The common problems these antennas seem to have is a narrow bandwidth and low overall gain and efficiency. Lots of different methods have been tried to solve these issues. A possible solution that seemed by many researchers is designing a stack array patch antenna, which increases the bandwidth and gain with the help of an array antenna.

The Yagi Uda antenna using low cost substrate technology (LTCC) in [3-4] achieves a maximum gain of 6 dBi. The Yagi Uda antenna of an array of 4×4 in [5] has a maximum gain of 18 dBi. However, these antennas contain a structure of multiple layers that are complex to fabricate. For the sake of easiness in fabrication some Printed log-periodic dipole array (PLPDA) antennas are designed in the mmwave frequency which provides enormous bandwidth with steady gain over the entire frequency range also the design is easy and simple to fabricate [6]. A planar fan-like antenna has also demonstrated in [7], which has a peak gain of 7.6 dBi for 60 GHz antenna.

A microstrip patch antenna operating at ka band with multiple resonant frequencies is proposed in this paper. This design elaborates one of the ways to accomplish high gain and wide bandwidth using a stacked patch antenna design. A compact and wideband feeding technology is implied to accomplish that goal. The antenna array has two layers, which allows the utiliziation of a standard fabrication process using PCB connector. The total size of the integrated array antenna is equivalent to the size of the radiating aperture, which is beneficial in miniaturizing the dimensions. The two main sectors [8-9] for future 5G enabled wireless patch antennas are Miniaturization and enlarging the beam width of patch antenna. Which most of the researchers suggest will be operating in millimetre-wave frequencies. Some previously done work by the researchers about 5G antenna/array designs have come to light recently [10-13].

A multiband antenna design is presented at the frequency range of 26-31 GHz. The design of the single band antenna contains a double layer of stacked array with a single patch with the feed and one resonator to increase the gain and bandwidth. Similarly, the dual band antenna design also comprised with a stacked array with two patches in the lower layer and dual resonator in the upper layer. The simulation results are fabricated later on and then tested with actual hardware. The results obtained from the test are demonstrations that the proposed antennas have high efficiency, wide bandwidth and high gain [14-15].

2. STACKED ARRAY ANTENNA DESIGN

A microstrip patch antenna with a stacked design structure has been designed in order to accomplish wide bandwidth and also higher gain for 5G antenna application system. Here, the structure is two-layered and implemented so that two stacked patches can be constructed on both substrate layers with a feeding circuit which is planar and on the first substrate in the lower patches that is shown in Figure 1. The patches in the lower state which serve as driving patches and are directly fed from a microstrip line and there is a matching circuit which matches the radiation impedance and also the feeding line (a 50 Ω) line. The specification of this structure can also be seen in this paper [4].

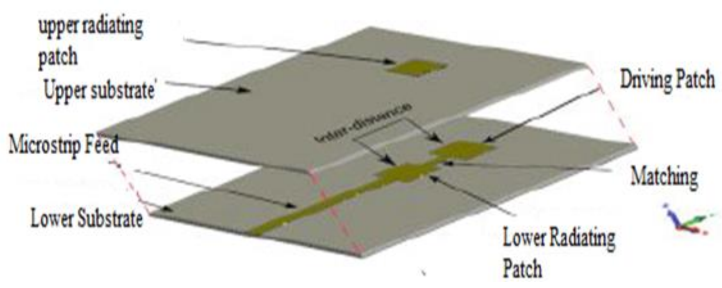


Figure 1. 2×1 Stacked series planar array antenna [8]

The antenna has been designed using two layers of Arnol Diclad 880 dielectric substrate which has a dielectric constant $\mathcal{E}$r=2.17 and the thickness is 0.252 mm. The width and the length or the dimensions of the substrate are 16 mm×16 mm. The feed line is a 50 Ω microstrip line which is attached to the patch. The lower substrate is completely grounded. The calculated dimensions were 2mm x 1.45mm of the lower layer patches (W×L) although the dimensions of the upper layer patches (WXL) are 1.8×1.2 mm respectively.

The equations of the transmission line is used here, which is provided by (1)–(6) in [8]. The usual equations of a rectangular microstrip antenna can be used to calculate anticipated Width (W) and Length (L),

At c is the speed of the light where, C=3 × 10^ 8 m/s
The operating frequency, f_0=28 GHz

Dielectric constant of the used substrate ϵ_r=2.17. The height of the dielectric substrate h=0.254

The height of the conductor (ht)
h_t=0.154

To find the width of the patch

$$W=\frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

To find the effective dielectric constant,

$$\epsilon_{reff}=\frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-0.5} \quad (2)$$

To find the fringing Length (ΔL)

$$\Delta L=0.142\,h\,\frac{(\epsilon_{reff}+0.3)(\frac{h}{W}+0.264)}{(\epsilon_{reff}-0.258)(\frac{h}{W}-0.8)} \quad (3)$$

To find the effective length

$$L_{eff}=\frac{c}{2f_0\sqrt{\epsilon_{reff}}} \quad (4)$$

To find the actual length of the patch

$$L_g=13.333+L \quad (5)$$

To find the width and the length of the ground

$$W_g=13.333+W \quad (6)$$

3. SINGLE BAND ANTENNA DESIGN

From the 6 equations mentioned above and with the help of the computer simulation technology (CST) using the stack series array concept of 1 radiating patch and 1 resonating patch is designed as configured in Figure 1 and shown in Figure 2.

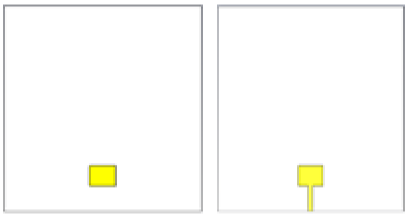


Figure 2. 1x 1Geometry of stack series array antenna, (a) top layer vies, (b) Lower layer view

Figure 2 shows a stacked series antenna array geometry. An antenna with a planar feed and two stacked patches in a substrate, which has two layers and the parameters of dielectric substrates and dimensions of driving patch, radiating patch and feeding circuit. Figure 2 presents the geometrical representation of the antenna array which is double-layered. The array antenna has been designed, simulated and optimized by Computer Simulation Technology (CST). The stack series array antenna has been designed by using with no air gaps between the two substrates. Table 1 shows the optimized dimensions of 1×1 stack series array antenna [9].

Table 1. Two stack patch dimensions (radiating and resonating patch)

Parameter Symbol	Description	Dimensions (mm)
L	Length of The substrate and the ground	32
Lf	Length of the feeding line	4
Lp	Length of the patch	3.14
W	Width of substrate and the ground	32
Wf	Width of the feeding line	0.7894
Wp	Width of the patch	4.27
T	Thickness of substrate	0.254
t1	Thickness of the patch+ ground + feeding line	0.072/0.035/0.017

Figure 3 shows the single band simulation results and of the stack array antenna and Figure 4 shows gain over frequency. The x-axis shows that frequency in (GHz) and y-axis represents the gain in (dB). At 28 GHz the maximum gain obtained is 7.592 dB. Figure 5 presents the radiation pattern of the designed antenna in single band.

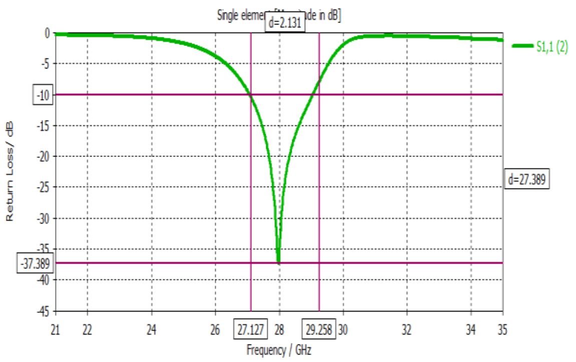


Figure 3. Simulation results of 1×1 single band stack series array antenna at (frequency 28GHz)

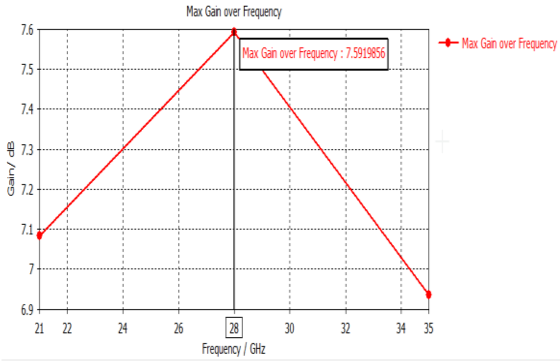


Figure 4. Gain over frequency for single band antenna

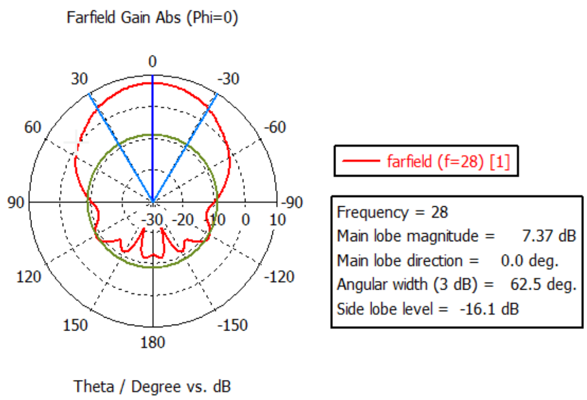


Figure 5. The radiation pattern of single band antenna

4. DUAL BAND ANTENNA DESIGN

As similar to the single band design, dual bands are achieved using 2 radiating patches in series and two resonators. The optimization and simulation are conducted using CST. Figure 6 illustrates the dual band stack series array antenna layout. The antenna has two layers; the top layer has two series patches which acting as parasitic element and the bottom layer has two elements with a 50 ohm feeding line. Table 2 shows the optimized dimensions of 2×2 stack series array antenna.

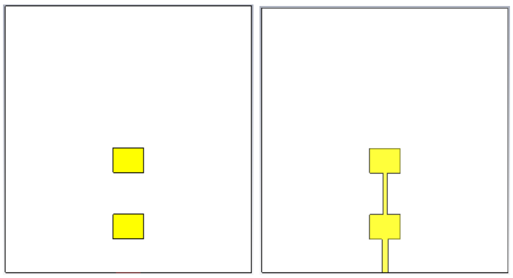


Figure 6. 2×2 Stack series array antenna

Table 2. 2×2 Stack series array antenna dimensions

Parameter Symbol	Description	Dimensions (mm)
L	Length of the substrate and the ground	32
Lf	Length of the feeding line	4
Lm	Length of the matching	5
Lp	Length of the patch	3
W	Width of substrate and the ground	32
Wf	Width of the feeding line	0.7894
Wm	Width of the matching	0.5
Wp	Width of the patch	4
T	Thickness of substrate	0.254
t1	Thickness of the patch+ ground + feeding line	0.072

Figure 7 shows the return loss versus the frequency achieved in simulations. A numerous optimization regarding the length and width of the patch has been done during the simulation. As a result of the optimizing the dimensions, a dual band frequencies of 27.5452 GHz and 29.5605 GHz are obtained. A wider bandwidth of 2.0153 GHz is also obtained. Figure 8 represents the gain for the operated frequency in the dual band [9].

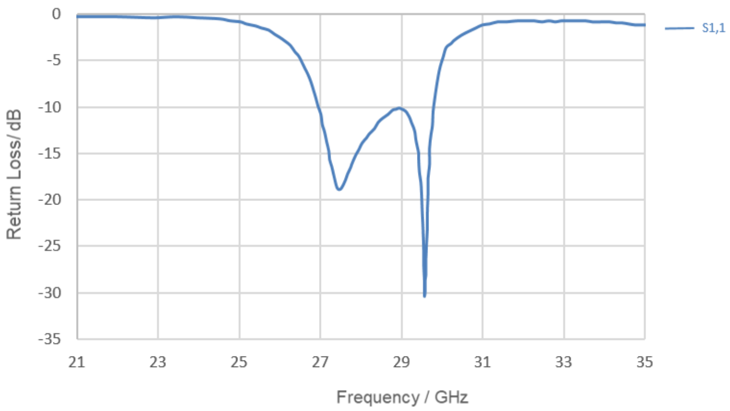


Figure 7. The return loss of 2×2 stack series array antenna over frequency

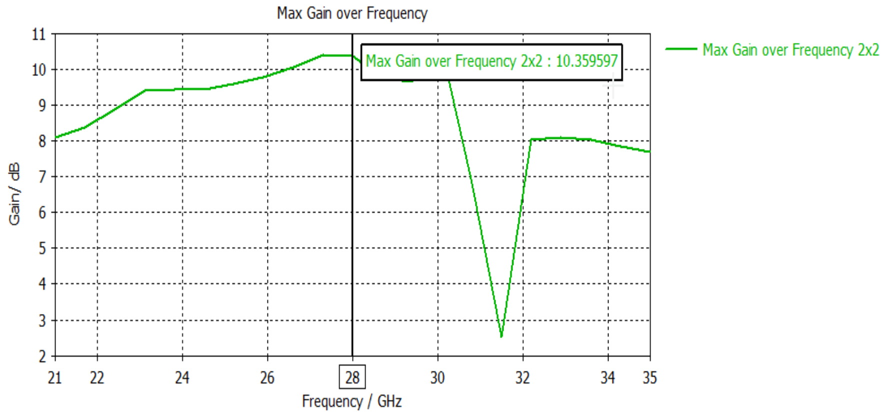


Figure 8. Gain over frequency for dual band antenna

5. TRIPLE BAND ANTENNA DESIGN

As similar to the single and dual band design the simulation results are extracted from CST and in the case of triple band we have used 5 radiating antennas and five resonators. Figure 9 presents the triple band stack series array antenna. The antenna also has two layers; the top layer has two series patches which acting as parasitic element and the bottom layer has two elements with a 50 ohm feeding line. In addition, Table 3 shows the optimized dimensions of 5x5 stack series array antenna.

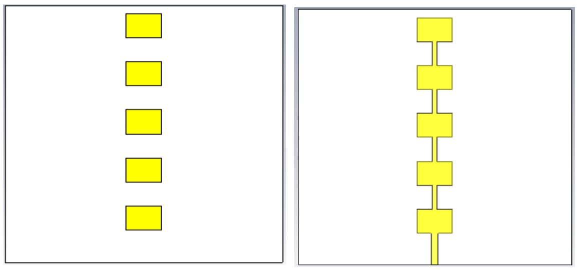


Figure 9. Structure visualization

Table 3. 5×5 Stack series array antenna dimensions

Parameter	Description	Value
L	Length of The substrate and the ground	32
Lf	Length of the feeding line	4
Lm	Length of the matching	3
Lp	Length of the patch	3
W	Width of substrate and the ground	32
Wf	Width of the feeding line	0.7894
Wm	Width of the matching	0.5
Wp	Width of the patch	4.13
T	Thickness of substrate	0.254
t1	Thickness of the patch+ ground + feeding line	0.035

Figure 10 represents that the simulation results of 5×5 stack series array antenna for ka-band. The antenna has five elements in the lower layer and another five parasitic elements in the top layer. As we can see in the fig.10 the antenna has triple band operational frequencies including 24.18 GHz, 26 GHz, and 28.453 GHz.

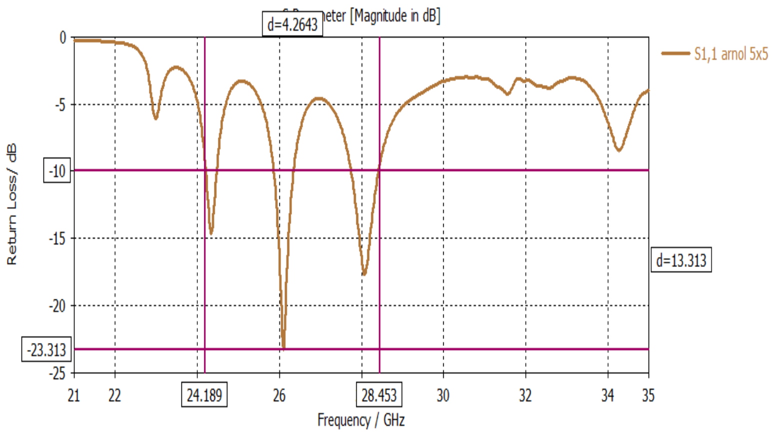
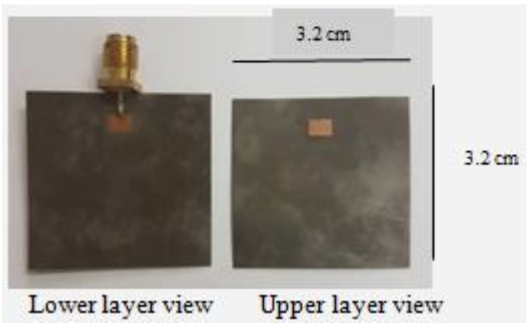


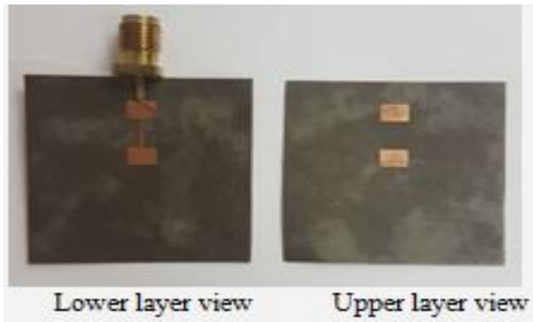
Figure 10. Triple band Simulation results for Ka-band antenna

6. FABRICATION AND TEST

The experimental results were conducted based on the Ka-band frequencies. The antenna is designed using two layers of RT rogers 5880 dielectric substrate having a dielectric constant of ϵr=2.17 and a thickness of 0.252 mm. A 50 ohm SMA connector was used during the fabrication of the antenna. There are several devices that can be tested for the antennas for example oscilloscope, Spectrum analyser and Vector Network Analyser (VNA). Vector Network Analyser machine was used for testing. VNA can be used to test from 10 MHz-50 GHz. In addition, Ka-band antenna ranges from 20-40 GHz, hence this device were used for testing purpose. Figure 11 shows the fabricated antenna of 1×1, 2×2 and 5×5 stack series array design.



(a)



(b)

(c)

Figure 11. Fabricated antennas, (a) 1×1 stack series, (b) 2×2 stack series array, (c) 5×5 stack series arary antenna

Figures 12, 13 and 14 shows the comparison of the resonances between the simulation and test results of single, dual band and triple band simultaneously. The Table 4 shows the details of the bandwidth and frequency comparison for the simulated and fabricated results in Ka band in single, dual and triple band.

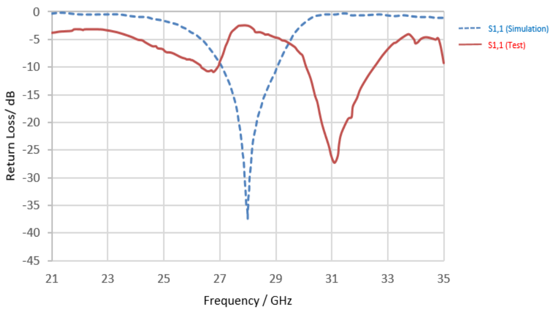


Figure 12. Comparison of Simulation and test results for Single band (31.14 GHz)

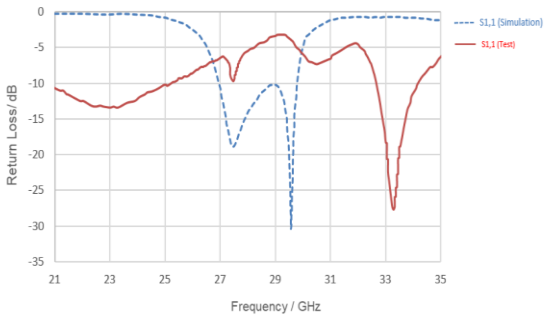


Figure 13. Comparison of Simulationand test results for Dual band (33.38, 38.98 GHz)

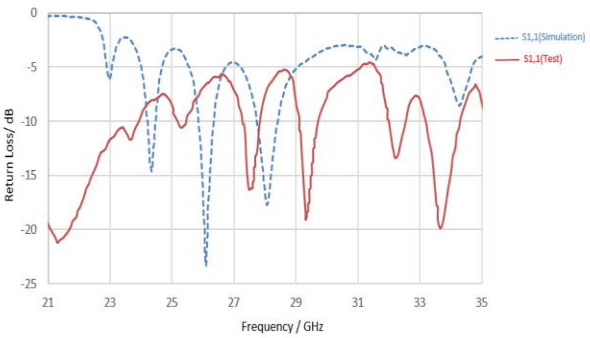


Figure 14. Comparison of simulation and test results for triple band resonances (27.52, 29.32, 33.7 GHz)

Table 4. Comparison between the bandwidth and frequency of Ka-band simulation and tested results

Band Type	Result type	Bandwidth	Operating frequency
Single band	Simulation	2 GHz	F=28GHz (simulation)
	Fabrication	2.5 GHz	F=31.14 GHz (fabrication)
Dual band	Simulation	2 GHz, 0.9 GHz	F=28GHz, and 30 GHz (simulation)
	Fabrication	N/A, 1.5 GHz	F=33.38, and 38.98 GHz (fabrication)
Triple band	Simulation	0.4 GHz, 0.5 GHz, 0.66 GHz	F=24.18, 26, and 28.453 GHz(simulation)
	Fabrication	0.25 GHz, 0.6 GHz, 0.7 GHz	F=27.52, 29.32, and 33.7 GHz (fabrication)

Vector network analyzer (VNA) have been used for the antenna fabrication, however the results obtained from fabricating process were somewhat changed from the results achieved from computer simulation technology (CST) simulations and the results were shifted to the right direction. But still we managed to achieve single, dual and triple band resonances in fabricated test results aswell. And we have investigated, the actual cause for the shifting of the frequency and have narrowed it down to three main reasons. Firsltly, as the operating frequency is 28 GHz the size of the antenna is smaller than usual, the length and width of our antenna is only 32 mm. Secondly due to the stacked structure of the antenna the fabrication process becomes more complicated. Thirdly the thickness of the antenna is very similar to the thickness of a paper which makes the fabrication process even tougher. Although we have some shifting in frequency we have managed to get the resonances from all the single, dual and triple band antennas, so the fabrication from the test results have been finalized.

7. CONCLUSION

Multiple band antenna has been designed up to triple band configurations for 5G applications operating at Ka-band. The proposed design has two layer of substrates with patches stacked in a series in each of the substrate with the aim of achieving a wideband/ multiband antenna. The elements in both the lower and upper patches have been increased and optimized in order to obtain from single to triple bands. Designed antennas can resonate at single band of (28 GHz), dual band (28 and 30 GHz), triple band (24.18, 26 and 28.453) with0.4 GHz, 0.5 GHz, 0.66 GHz bandwidth for triple band 0.9, 2.0 GHz for dual band and 2.0 GHz for singleband. 7.6 dB and 10.4 dB, 12.940 dB gains are also obtained in single, dual and triple band antennas. All the antennashave been fabricated, tested and matched with simulation results and found similar behaviors. The proposed antenna have demonstrated a decent possibility for 5G millimeter wave (mmwave) applications.

AKNOWLEDGEMENTS

This work is partially funded by International Islamic University Malaysia (IIUM) Publication RIGS grant no. P-RIGS19-003-0003.

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