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Array Antenna for Wireless Access Points and Futuristic Healthcare Devices

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Abstract: A design of a low-profile and printed array antenna for wireless access points and futuristic healthcare devices is presented in this manuscript. The antenna design is derived from a printed dipole configuration and is optimized using an empirical design approach to achieve enhanced bandwidth, gain and efficiency performances. The antenna is printed on Rogers RT-5880 laminate with a permittivity of 2.2 and a thickness of 0.508 mm. The overall footprint of the design covers 27.5×39.1 mm^2 on a substrate of 36×42 mm^2. Results have shown that the design covers a wide bandwidth of more than 7 GHz, making it capable of covering 40.5–42.5 GHz, 42.5–43.5 GHz, 45.5–47 GHz and 47–47.2 GHz 5G bands as recommended in WRC-15. The design shows an average gain of 11.5 dB and an average efficiency of 84% over the entire bandwidth. The simulation and measurement results mostly agree, with minor disparities which might have been caused due to substrate tolerance and testing setup.

Keywords: 5G; array antenna; MIMO antenna; millimeter wave; digital health

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1. Introduction

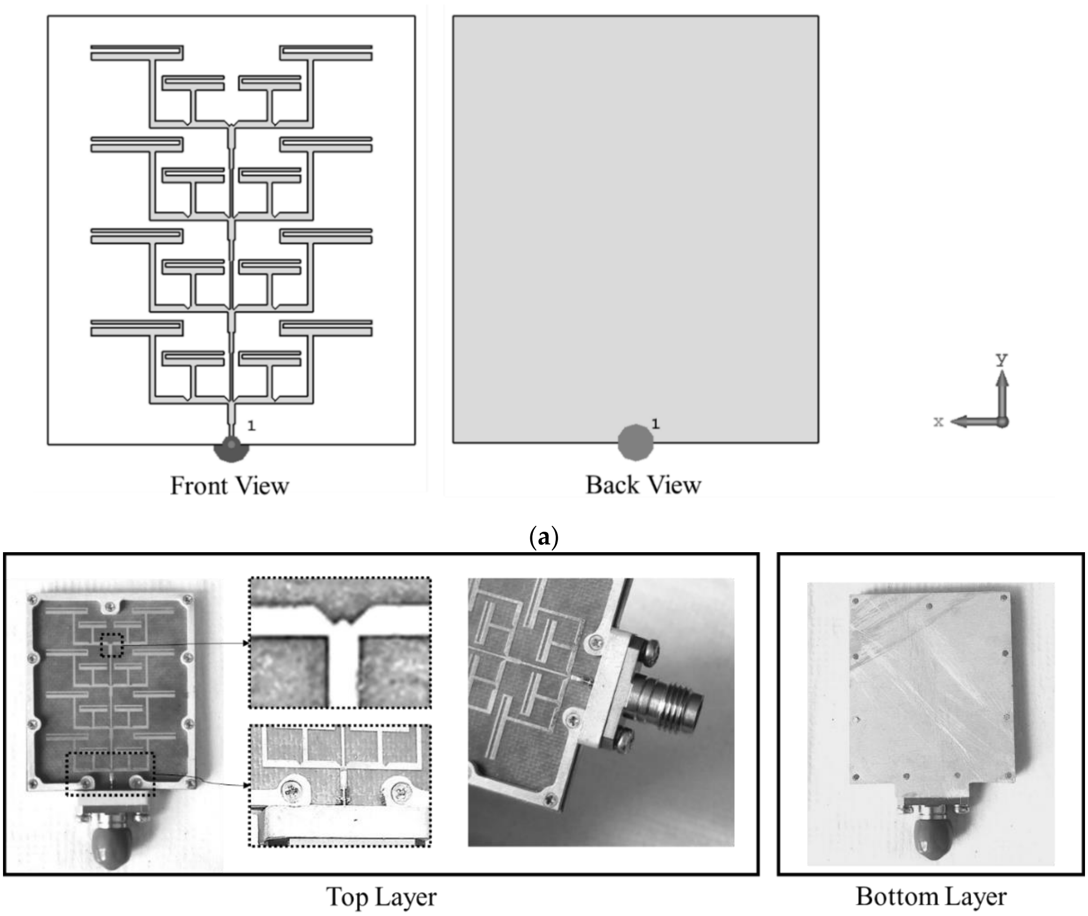
The evolution of wireless communication standards dates back to 1979 when the first generation (1G) of wireless communication was introduced. The handsets in those days were able to cover analog services with a very narrow frequency bandwidth, thus serving a very limited number of users [1]. With the growth in the demand for wireless communication, the second generation (2G) GSM system was launched in 1991 which showed an enhanced bandwidth and digital voice encryption [1]. The number of users greatly increased and wireless voice communication captured the interest of the world [2]. Data communication, however, was not possible and soon the need for data protocols became a necessity which gave rise to third generation (3G) and fourth generation (4G) wireless systems [2]. The number of users accommodated by these protocols jumped to millions and on-the-go data communication became possible [3]. From 1G to 4G, the frequency of operation shifts from lower frequency to higher frequencies, making it possible to have portable pocket-held or hand-held devices [4]. Wireless communication is not limited to mobile communication anymore and it can be anticipated that in future healthcare devices will be able to send and receive data wirelessly, making remote monitoring and treatment possible. Wireless communication has already started to produce solutions for supporting medical professionals over the last few years. The major applications in which radio wave propagation is helping the medical field are wireless imaging using high-frequency waves, wireless health monitoring and RFID support for physically disabled people [5–8]. This has created another challenge for wireless communication engineers to make such devices that can support seamless communication in dense indoor environments such as in a hospital or a care home. An example of wireless health applications is presented in [5]. In this paper, a Bluetooth-based fall detection and warning system has been proposed for elderly people. Another interesting work has been presented in [7] where the authors have proposed an idea of monitoring cardiovascular health remotely using IoT. The health sector needs digitization to reduce the load on hospitals. After the COVID-19 pandemic, it has been realized that there should be a digital health system where patients can be monitored and treated remotely and hospitals should be kept available for vulnerable and seriously ill people [9]. Remote health monitoring can be made more efficient if patients' health data are available on the go. For this purpose, health monitors need to be portable and lightweight so that it is easier to carry the battery-powered equipment. Therefore, for ever-increasing engineering and medical applications of wireless communication, the use of higher frequency bands has become a necessity [10]. The latest wireless communication technologies such as 5G can be employed for transferring patients' data from one place to another. The millimeter wave spectrum of 5G communication can be used to provide this operation seamlessly from ultra-portable terminals [10]. Though the introduction of 5G can make communication better, there are certain shortfalls which then need to be dealt with to achieve better-quality communication from a small battery-powered device. The wavelength in a millimeter wave spectrum is usually very small which makes signal attenuation and fading a major problem in dense terrains such as in urban indoor and outdoor communication environments [11]. Additionally, handsets and wireless terminals come with antennas inside the housing which affects their radiation performance [4]. It is thus very important to bring innovation and improvement to the current wireless communication circuitry, especially the antennas. This paper presents a new design of an antenna system for 5G frequencies. Conventional low-gain antennas are unable to provide high gain over large bandwidths and are thus not suitable for 5G and beyond 5G terminals [12]. In order to mitigate the effect of fading, modern transmission technologies such as MIMO and array can be used. Antenna systems supporting MIMO and array configurations can provide high gain and efficiency over wider frequency bandwidths such as those in 5G [12]. Additionally, devices working at very high frequencies will be of much smaller size which makes it a challenge to accommodate multiple antenna systems inside the device housing [13–15]. It is thus a very important research assignment to design such antennas for ultra-slim access points and portable terminals.

Various designs of antennas for 5G terminals are presented in [16–31]. The designs presented in the literature are mostly for lower frequency bands, whereas there are few designs for higher frequency millimeter wave bands. It has been deduced from the literature that the majority of the designs offer small bandwidth, low realized gain and efficiency. The designs with enhanced gain and efficiency performances over wider bandwidths in the millimeter wave spectrum are very few which makes it a necessity to design such antennas for smart wireless terminals [32].

In this article, a design of a high-gain array antenna for wireless access points and futuristic wireless healthcare devices is presented. The design is low profile and able to provide an improved gain and efficiency. The design will cover devices such as wireless routers, wireless endoscopes, wheelchairs, walking aids, oximeters and other medical sensors and scanners. The antenna design can be implemented practically to enable health devices to transmit and receive health data wirelessly to and from hospitals. The design along with its modeling and testing results will be discussed in the coming sections.

2. Antenna Design

The proposed design of an array antenna system for 5G communications is shown in Figure 1. The design is modeled and simulated in CST® MWS which uses the finite integration technique (FIT) to solve complex electromagnetic computations.



(**a**)

(**b**)

Figure 1. Array antenna for wireless terminals. (**a**) Computer model. (**b**) Manufactured model.

It can be seen from Figure 1 that the model is composed of eight major elements and eight minor elements. Each element is based on a printed and modified dipole configuration and the dimensions have been optimized using an empirical design approach through repetitive simulations. The antenna is printed on the top layer of Rogers RT5880 laminate with a 2.2 dielectric permittivity and a height of 0.508 mm. The ground plane of the design is on the back side and is a completely copper layer. The overall footprint of the design covers 27.5 × 39.1 mm^2 on a substrate of 36 × 42 mm^2. Each major element of the design is 9 × 8 mm^2, whereas each minor element is 6 × 4 mm^2. The manufactured model of the proposed design is shown in Figure 1 which presents a microstrip pattern printed on the top layer of the substrate and a complete ground plane on the bottom layer. The prototype is composed of three parts: a PCB, an RF connector and a metallic housing. The microstrip pattern on the PCB was etched using a CIF Technodrill PCB milling machine whereas the input RF connector used in the prototype was a 2.4 mm type female connector. The metallic housing was built to complete the ground plane of the antenna design.

The design flow for the presented design is presented in Figure 2 which shows how the antenna is designed from a basic printed dipole element. The various parameters of the model are shown in Table 1. The length of the printed dipole designed in step 1 is approximately 1 λ at 45 GHz frequency.

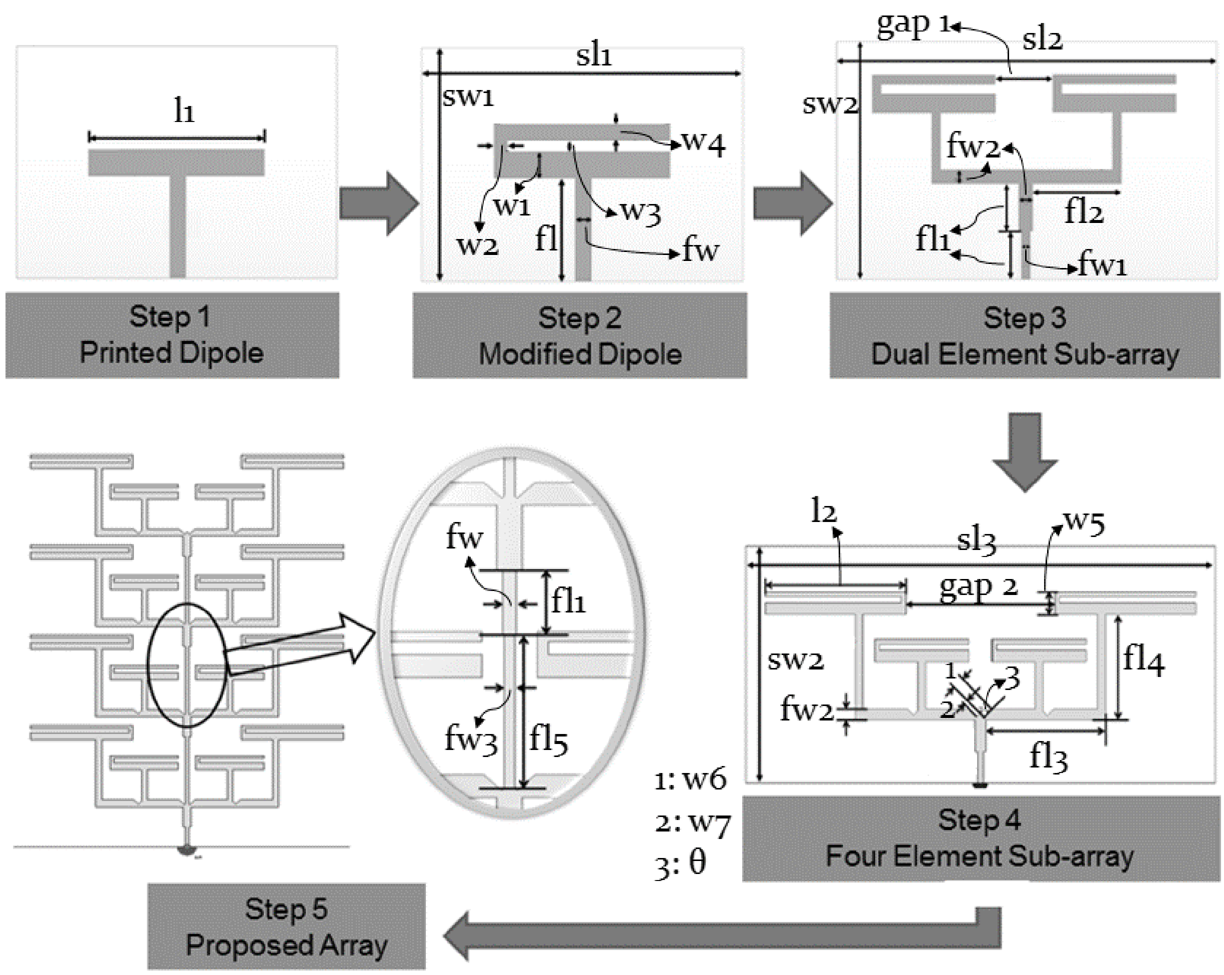


Figure 2. Design flow of the array antenna for wireless terminals. Units: mm.

Table 1. Various dimensions of the proposed array antenna.

S. No.	Antenna Dimensions					
	Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
1	sl_1	10.00	sl_2	18.00	f_{l3}	7.65
2	sw_1	6.00	sw_2	12.00	f_{l4}	6.70
3	l_1	6.00	f_{l1}	2.00	l_2	9.0
4	f_l	3.00	f_{l2}	3.65	w_5	1.40
5	f_w	0.50	f_{w1}	0.35	w_6	0.69
6	w_1	0.70	f_{w2}	0.70	w_7	0.30
7	w_2	0.20	gap_1	1.50	θ	90°
8	w_3	0.40	sl_3	36.00	gap_2	9.50
9	w_4	0.30	sw_3	15.00	f_{l_5}	4.73
10	f_{w_3}	0.30				

The design flow in Figure 2 shows five distinct steps in which a one wavelength dipole antenna is transformed into the proposed array. The target is to achieve a frequency bandwidth of more than 7 GHz with gain of more than 11 dB and efficiency of more than 80%. The design flow starts with the design of a simple dipole antenna printed on Rogers RT5880 laminate. The dipole is then transformed into a modified and folded dipole configuration to increase the gain and the frequency bandwidth. The antenna design is further progressed to step 3 in which a dual element sub-array design is presented which gives better gain and bandwidth than the previous step. The design is further improved in step 4 and step 5 to achieve the desired bandwidth, gain and efficiency performances. A comparison between different configurations of the design flow is shown in Table 2.

Table 2. A comparison between different configurations of the design flow.

Design Step	Comparison Parameter		
	Average Efficiency	Average Gain	6 dB Bandwidth
1	77.0%	5.52	2.5 GHz
3	80.0%	7.98	4.0 GHz
5	84.1%	11.52	7.8 GHz

It can be seen from Table 2 that the proposed design gives a larger bandwidth, a higher gain and a better efficiency than the other configurations. The proposed array antenna is low profile and it is deemed suitable for futuristic wireless access points and healthcare devices. The design was then simulated and tested and the results will be shown in the coming sections.

3. Simulation and Experimental Results

The design is modeled and run in CST MWS for the simulation results, whereas the testing results of the antenna were obtained from the antenna laboratory at Xidian University, China. Various simulation and measurement results will be discussed in the coming sub-sections.

3.1. S-Parameters

The simulated and tested S-parameters S11 of the proposed array antenna are shown in Figure 3. It can be seen from Figure 3a that the antenna is resonating with a large 6 dB frequency bandwidth ranging from 40.5–48.3 GHz. The antenna is thus capable of covering 40.5 GHz to 42.5 GHz, 42.5 GHz to 43.5 GHz, 45.5 GHz to 47 GHz and 47 GHz to 47.2 GHz 5G bands as recommended in WRC-15 [33]. The tested S-parameters of the antenna are obtained by connecting it to a calibrated vector network analyzer and the graph is presented in Figure 3b. The measured bandwidth ranges from 40.7 GHz to greater than 50 GHz, thus covering the aforesaid 5G bands of communication.

3.2. Radiation Performance

The simulated 2D and 3D radiation pattern of the proposed array antenna at different frequencies is shown in Figure 4. It can be seen that the radiation pattern is directional and the peak radiation lies perpendicular to the plane of the array, thus making it a broadside array. The radiation pattern of the proposed array antenna after testing is shown in Figure 5. The measured radiation patterns were extracted from an anechoic chamber as 2D Cartesian plots. It can be seen from the E-plane and H-plane radiation patterns that the array possesses a fairly directional radiation pattern. Moreover, the testing results approximately match with the simulation results, making the design more realizable in practice.

3.3. Antenna Gain

The simulated and tested antenna gain at different frequencies is shown in Table 3. The gain is calculated using a standard method of gain comparison [34]. The simulation results agree well with the measurement results. The average gain thus covered by the antenna is 11.5 dB in simulations, whereas in measurements it is 10 dB.

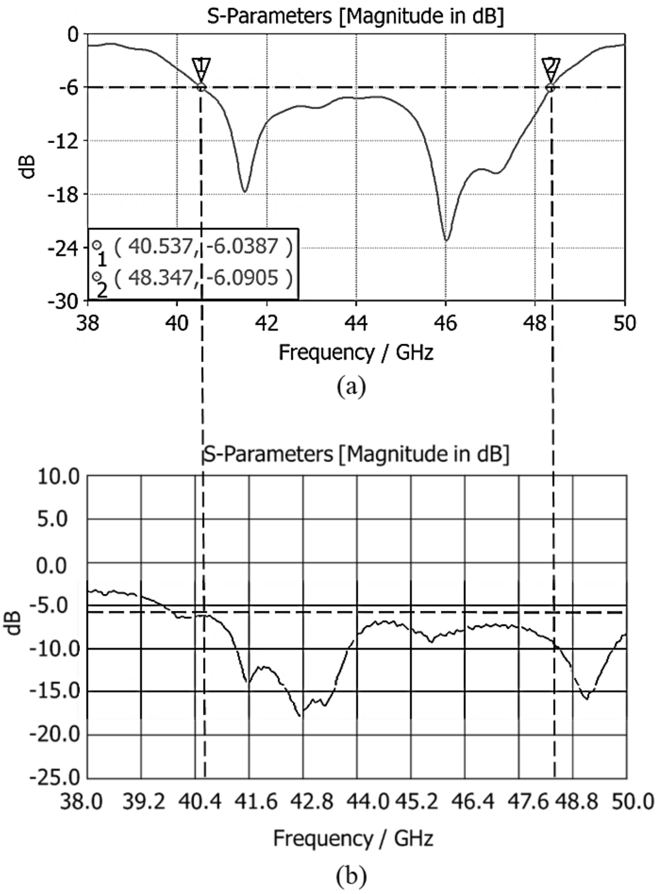


Figure 3. S-parameters (S11) of the proposed array antenna. (**a**) Simulated S-parameters. (**b**) Tested S-parameters.

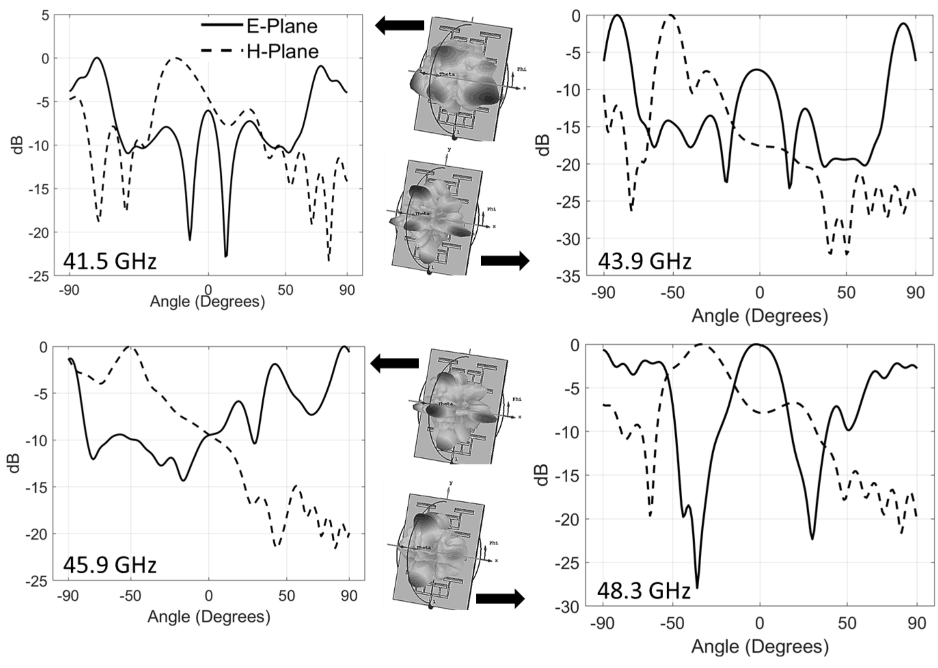


Figure 4. Simulated radiation pattern of the proposed array antenna.

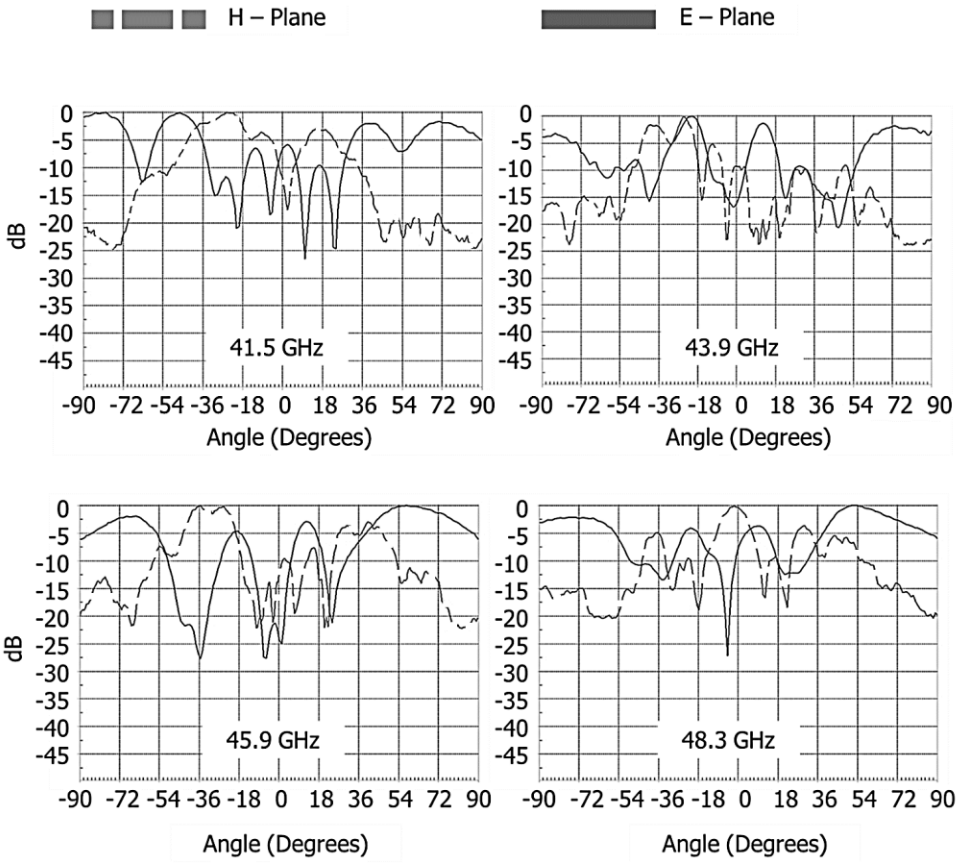


Figure 5. Measured radiation pattern of the proposed array antenna.

Table 3. Gain and efficiency of the proposed array antenna at different frequencies.

Freq. (GHz)	Antenna Gain (dB)		Efficiency (%)
	Simulated	Measured	Simulated
40.5	8.66	7.50	70
41.5	10.14	8.60	91
43.9	12.61	10.5	79
45.9	12.25	10.6	92
47.0	13.72	11.2	93
48.3	11.78	11.6	76

3.4. Antenna Efficiency

The simulated efficiency of the proposed array antenna at different frequencies is shown in Table 3. The average value of efficiency thus achieved over the entire bandwidth is approximately 84% which makes the design suitable for futuristic access points and terminals.

3.5. Surface Current Distribution

The simulated surface current distribution of the proposed array antenna is shown in Figure 6. It can be seen that the lower rows of the array contribute more towards the radiation as compared to the upper rows at both frequencies of observation. The upper elements of the antenna array make the radiation pattern directional, thus contributing more towards the enhancement of the antenna's directivity and gain.

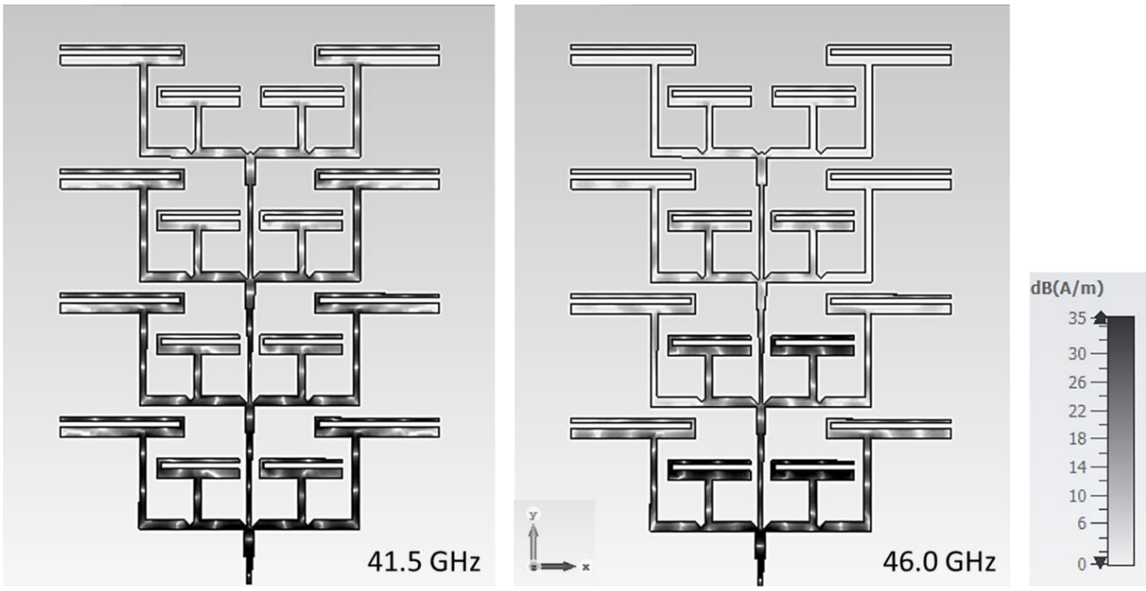


Figure 6. Surface current distribution of the proposed array antenna.

3.6. Effect of Notches and Cuts

The proposed design includes notches and cuts near the feeding point in each array element. The dimensions of these notches and cuts have been selected empirically through parametric analysis in CST Microwave Studio. Simulations have shown that these notches and cuts change the distribution of the surface current and contribute towards an enhancement in the overall bandwidth. Moreover, they also improve the gain of the antenna, especially at the edge frequencies. The gain improvement with the introduction of these notches and cuts is, however, not significant and it is approximately around 5.5%.

3.7. Performance Comparison

A comparison of the proposed antenna with some of the similar designs in the literature is presented in Table 4. It can be seen that the antenna presents an overall better performance.

Table 4. Gain and efficiency of the proposed array antenna at different frequencies.

Citation	Shape/Type	Size	Fractional Bandwidth	Average Gain
[16]	Multilayer Printed Microstrip	15 × 13	0.18	7.00 dB
[29]	Multilayer SIW-Based Microstrip	33 × 18	0.20	9.00 dB
[35]	Printed 8-Element MIMO	31 × 31	0.15	6.40 dB
[36]	SICL-Excited SIW Patch Antenna	30 × 60	0.18	8.60 dB
[37]	CP Antenna Array	30 × 30	0.14	8.00 dB
[38]	Dual-Dipole SIW	10 × 40	0.32	3.00 dB
[39]	Tapered Slot, SIW	20 × 70	0.07	12.0 dB
Proposed	Printed Microstrip Array	28 × 40	0.18	11.5 dB

4. Conclusions

A new design of an array antenna for wireless access points and digital health terminals is presented along with the simulation and the measurement results. The design is composed of eight major and eight minor elements each realized from a modified printed dipole configuration. The design gives a large bandwidth of around 8 GHz in the frequency spectrum of 40–50 GHz, thereby covering several 5G bands. The simulation and measurement results strongly agree, except for a few changes which might have been caused due to substrate tolerance, fabrication precision and the testing setup involving the connecting cables and the connectors. The design is small and low profile, making it suitable for millimeter wave 5G devices for engineering and medical applications. Further modifications in the design will be made in future to reduce the antenna size and to enhance the antenna gain. Additionally, improvements will be carried out to achieve a wider 10 dB frequency bandwidth. Moreover, an in-depth analysis including aperture efficiency and SAR measurement will be included in the immediate future work. Finally, on-body testing will be carried out to examine the compatibility of the antenna with body-worn medical devices.

Author Contributions: R.Y.K. presented the idea, performed the experiments and prepared the manuscript. Q.A. contributed to the supervision of the research work, S.S.'s contributions include prototype development and measurements and M.H. contributed to reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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