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Multiband Handset Antenna System for UMTS/LTE/WLAN/ Sub-6 5G and mmWave 5G Future Smartphones

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Abstract

In this paper, a new antenna system for rapidly emerging multifunction devices is presented. The proposed antenna system consists of four antenna components each one operating at different frequency bands separately. The designed antennas are isolated and integrated on a single substrate. The first antenna is designed to operate at 1920–2170 MHz covering the UMTS band, whereas the second antenna is proposed for the lower band 5G systems and WiMAX operating within the frequency range of 3.4–4.2 GHz. Furthermore, another antenna is designed to cover the higher band 5G system and the IEEE 820.11a WLAN within the frequency range of 5.1–5.85 GHz. Finally, a 28 GHz bowtie-based MIMO antenna array is designed and simulated for the mmWave future 5G mobile networks. The proposed antennas were designed and simulated by using CST microwave studio. The results showed that all of the proposed antennas exhibited excellent reflection characteristics below −20 dB at the resonant frequency and achieved high radiation efficiency reached 99% in some cases with a peak gain ranging between 4–6 dBi. The proposed antenna system helps smartphones to perform multitasks and achieve a better-quality operation especially with the enormous growth of IoT techniques.

Keywords

5G, smartphone, sub-6 GHz, UMTS, LTE, WLAN, mmWave

1 Introduction

Nowadays, smartphones are becoming important and extremely needed as multifunction devices and perform multitasks instantaneously [1]. Smartphones have been rapidly developed during the last decade where many services have been added and integrated into one single device. This has been accomplished by incorporating several technologies in one device such as the global system for mobile communication (GSM), 3G & 4G, Wi-Fi, and Bluetooth [2, 3]. By increasing the demand on utilizing more applications of the internet of things (IoT), another demand is emerged on designing systems that provide high data rates to cope with the rapidly emerging IoT requirements. In addition, mobile real-time video calls are dominating the mobile services recently (especially during the COVID-19 pandemic) where many of these calls are utilizing the internet services provided by mobile operators, which require high data rates and efficient data transmission that also depends on the physical layer of the system. Fortunately, with the increasing usage of real-time video calls, the screens of these devices are getting wider and larger for better resolution and user experience compared to the old generations of mobile phones. Furthermore, with the recent advancement of integrated circuits, the internal components of the device are now smaller in size and occupy less internal area. Due to all of the aforementioned factors, there are now plenty of areas inside the device to implant an efficient antenna system that can cover all the frequency bands and provide the required data rates. Thus, printed antennas are the best candidate to fit within relatively wide and thin devices.

The emergence and development of IoT applications and the need for mobile internet with high speed have motivated researchers and mobile manufacturers around the world to give the priority to finding feasible and efficient solutions to meet such requirements. The IoT issue needs an antenna system that operates at different operating bands and resonant modes to increase the number of devices connected simultaneously, whereas, on the other hand, the need for high-speed data communication can be addressed by employing mmWave 5G technologies with MIMO technology to enhance the system capacity.

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Thus, designing 5G antenna elements with keeping the existed 2G, 3G and 4G in one device is a challenging topic for antenna engineers [4–6]. Hence, in this paper, a compact multiband antenna system consisting of four integrated components is designed and optimized to cover UMTS, LTE, WLAN, sub-6 5G, and mmW 5G applications. The proposed antenna system is designed to operate specifically at the following bands: 1920–2170 MHz covering the UMTS [5, 7] and WWAN/LTE [8] as well as the other 4G frequency bands [9], 3.4–4.2 GHz covering the WMAX [10], 5.1–5.85 GHz covering the IEEE 802.11a WLAN [11] and the LTE band 45 and finally 28 GHz for the mmWave 5G system [9, 12, 13].

The remainder of this paper is organized as follows: Section 2 presents the antenna part that resonates at the lower band of the proposed antenna system (1920–2170 MHz). Section 3 introduces the antenna structure that resonates at 3.4–4.2 GHz, while Section 4 illustrates with detail the part that operates at 5.1–5.85 GHz. Finally, in Section 5, the bowtie-based MIMO array is presented, whereas, Section 6 concludes the outcome of this work.

2 Structure of the proposed antenna system

The proposed antennas were designed and simulated by using CST microwave studio. The antenna structure is placed on an RT/Duroid 5880 substrate with a dielectric constant of 2.2 and a thickness of 0.787 mm. All antenna components are placed on one face of the substrate close to each other and fully integrated into the on-plane ground as shown in Fig. 1. The width of 80mm and length of 160 mm were chosen based on the standards of many mobile phones manufacturer.

As can be seen from Fig. 1, the system includes four antenna components operating separately at different frequency bands. It is also seen that the higher the frequency band the smaller the antenna structure. For Antenna 4, it has been chosen an array of bowtie elements operating at 28 GHz to cover the mmWave 5G band. In the following, each antenna element will be discussed in detail showing the structure with dimensions, *S*-parameters, and radiation pattern.

For Antenna 1, the geometrical structure is quite simple and compact providing a wide performance (1920–2170 MHz) and an easy fabrication property as there are no fine details or rounded corners. The detailed structure and dimensions of Antenna 1 are illustrated in Fig. 2. Table 1 shows the geometrical dimensions of Antenna 1.

The designed antenna is resonating within the frequency range of 1920–2170 MHz covering the UMTS and LTE bands as shown in Fig. 3. The antenna is also supporting the digital communication system (DCS) and WLAN systems with a reflection coefficient below −10 dB at 1.8 GHz and 2.4 GHz, respectively. In addition, Fig. 4 demonstrates the gain and efficiency of the lower band proposed antenna.

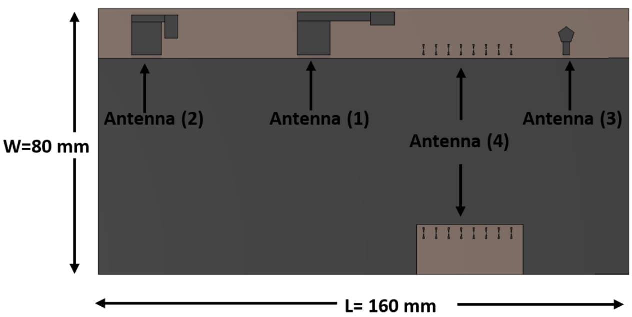

Fig. 1 Proposed handset antenna system

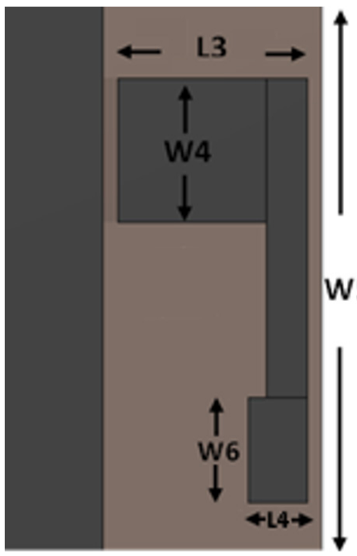

Fig. 2 Geometrical structure of Antenna 1

Table 1 Optimized design parameters for Antenna 1 (in mm)

*L*3	*L*4	*W*4	*W*5	*W*6
13	4	9.9	29.26	7.27

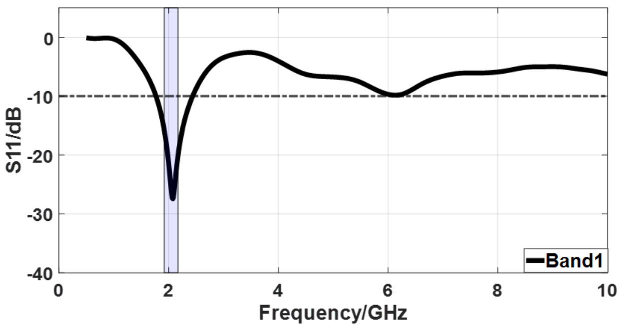

Fig. 3 *S*11 versus frequency of Antenna 1

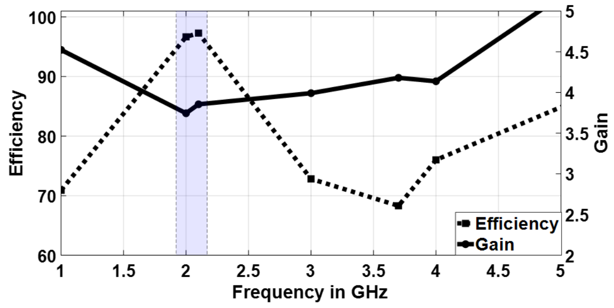

Fig. 4 Efficiency and gain of Antenna 1

Fig. 4 reveals that the antenna exhibits high efficiency (above 95%) at the frequency band of interest. On the other hand, the antenna showed an acceptable gain (higher than 3.5 dBi). It is worth mentioning that the lower band proposed antenna exhibits an almost omnidirectional radiation pattern as depicted in Fig. 5.

3 Lower band 5G sub-6 GHz antenna

In this section, the antenna part (Antenna 2 in Fig. 1) that is responsible for the middle 5G band (3.4–4.2 GHz) is presented and discussed. As for Antenna 1, Antenna 2 is also compact and easy to fabricate with not many fine details where the same geometrical concept is also applied to Antenna 2 as shown in Fig. 6. Table 2 shows the geometrical dimensions of Antenna 2.

The *S*11-parameter versus frequency for Antenna 2 is depicted in Fig. 7. It is clearly demonstrated that the designed antenna is well resonating within the frequency band of interest (3.4–4.2 GHz). This makes it a preferable choice for the lower band of the 5G sub-6 GHz mobile systems with reflection characteristics that go below −20 dB.

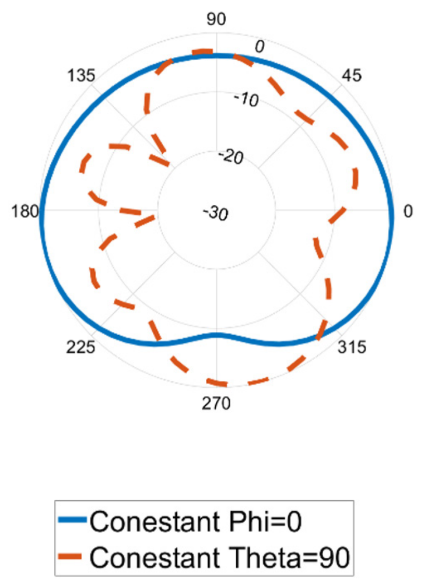

Fig. 5 Radiation pattern of Antenna 1

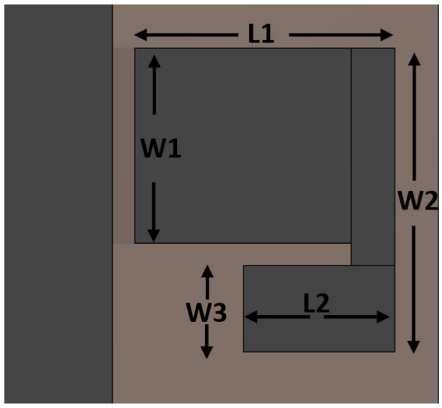

Fig. 6 The lower band 5G antenna (Antenna 2)

Table 2 Optimized design parameters for Antenna 2 (in mm)

*L*1	*L*2	*W*1	*W*2	*W*3
12	7	9	14	4

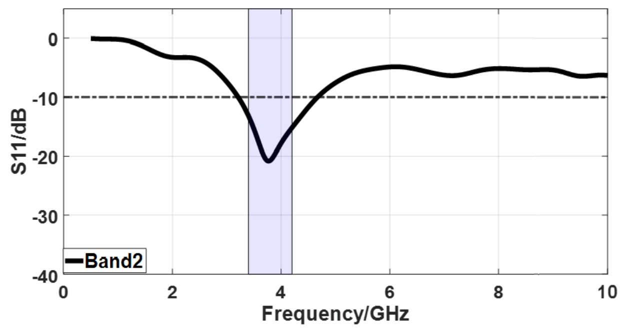

Fig. 7 *S*11 versus frequency of Antenna 2

Antenna 2 has exhibited an excellent efficiency that exceeded 99% within the frequency range of 3.4–4.2 GHz and has reported a peak gain between 4.5–5.25 dBi within the aforementioned frequency range as shown in Fig. 8. In contrast, Antenna 2 has also shown an almost omnidirectional radiation pattern as illustrated in Fig. 9.

4 Higher band 5G sub-6 GHz antenna

It is well known that there are several frequency bands are proposed for the future 5G mobile networks. One of these suggested bands is the 5.1–5.85 GHz band. Furthermore,

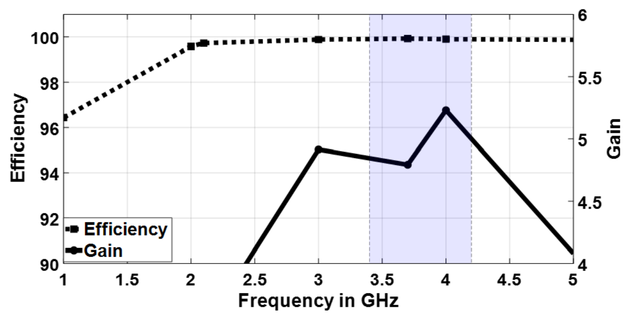

Fig. 8 Efficiency and gain for Antenna 2

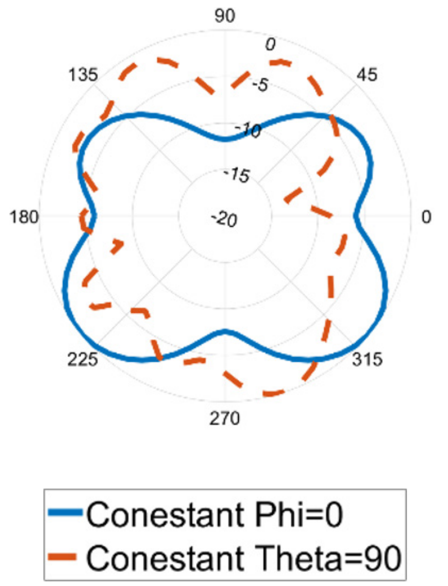

Fig. 9 Radiation pattern of Antenna 2

this frequency band covers also the IEEE 802.11a WLAN system and the LTE band 46. Thus, a compact antenna (Antenna 4) is designed to operate within this frequency band as shown in Fig. 10. Antenna 3 has a very simple geometry and it is well integrated within the overall antenna system. The geometrical dimensions of Antenna 3 are; $L5$ = 4 mm and $L6$ = 2.94 mm. Moreover, Fig. 11 illustrates the S-parameters of Antenna 3 showing the antenna performance at the frequency range of interest (i.e. 5.1–5.85 GHz).

The proposed higher band 5G antenna exhibited a constant efficiency above 95% within the aforementioned frequency range with a reported peak gain between 6–7 dBi

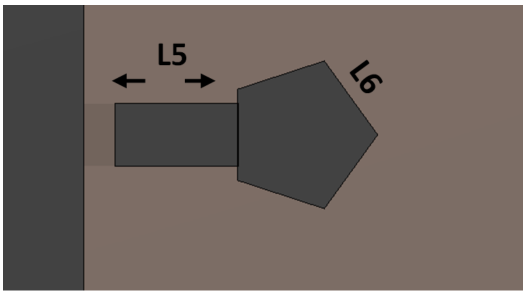

Fig. 10 Structure of Antenna 3

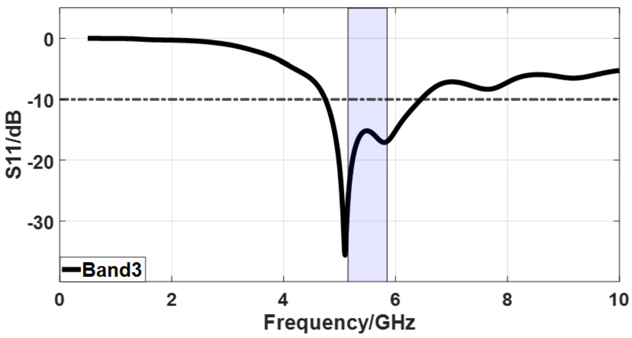

Fig. 11 S11 versus frequency of Antenna 3

as depicted in Fig. 12. These simulation results indicate that this antenna design is a promising candidate for future 5G systems due to its compact size, high gain, efficiency, and its excellent reflection characteristics. Furthermore, the proposed 5G antenna has shown a great omnidirectional radiation pattern making it a potential design for this application as shown in Fig. 13.

5 The mmWave 5G antenna

With the increasing demand for higher bandwidth systems and higher data rates, researchers worldwide were busy in the last decade exploring the feasibility of the mmWave band to meet such requirements. One of the frequency bands that was extensively investigated is the 28 GHz band with the possibility of employing a MIMO array instead of a single element. MIMO arrays for 5G

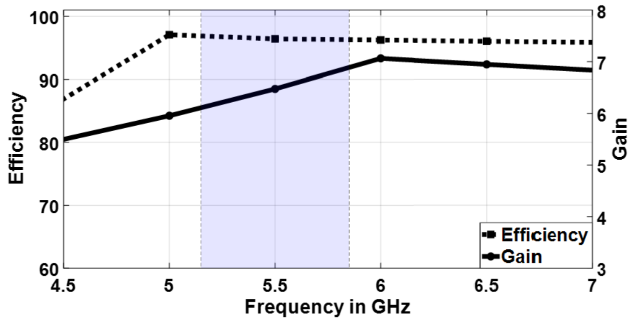

Fig. 12 Efficiency and gain of Antenna 3

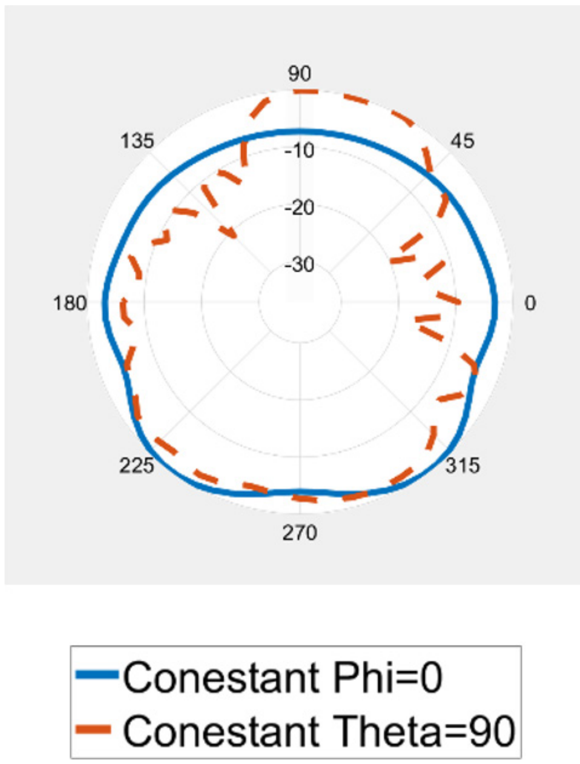

Fig. 13 Radiation Pattern of Antenna 3

applications at mmWave bands could offer up to 1Gbps data rate anywhere for high mobility devices with realizing point-to-point communication between the mobile phone and the nearby base station. Thus, the antenna system in this work has included a 2 × 8 bowtie-based MIMO array to operate at 28 GHz. The structure of the single element and the arrangement as linear array for Antenna 4 with their dimensions are shown in Fig. 14.

The $S11$-parameter of the proposed mmWave array (Antenna 4) is shown in Fig. 15. It can be seen that the designed array offers a wideband operation covering a broad range of suggested frequencies for 5G applications with return loss just above −20 dB for the entire 28 GHz band. On the other hand, the proposed bowtie array has exhibited a perfect radiation efficiency at 28 GHz and reported a constant gain over a wide range of mmWave bands reaching 5 dBi as illustrated in Fig. 16. These reflection and radiation characteristics make the proposed mmWave bowtie array a perfect choice for the future 5G mobile handsets.

It has been clearly explained throughout this paper that it is possible to integrate several antenna components operating at different frequency bands on one single substrate. This enables the device to work effectively

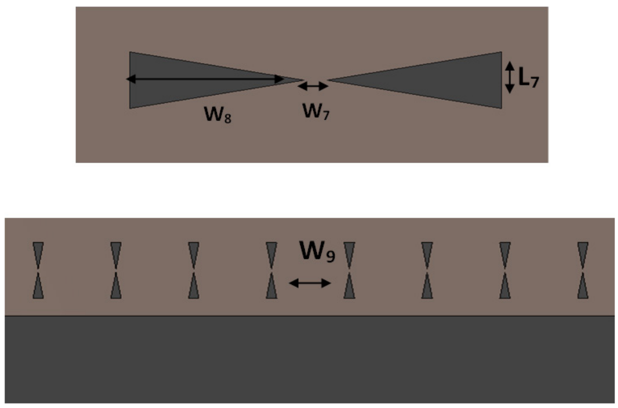

Fig. 14 Bowtie linear array at 28 GHz, $W7$ = 0.2 mm, $W8$ = 1.55 mm, $W9$ = 3.77 mm, and $L7$ = 0.5 mm

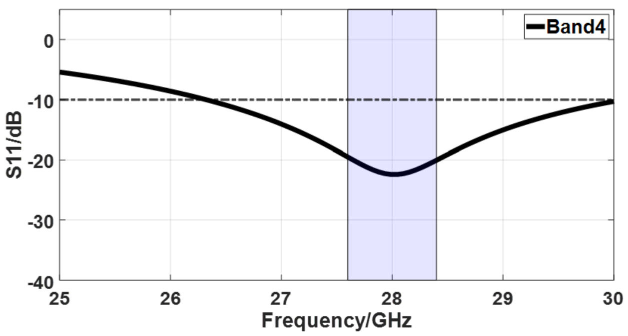

Fig. 15 $S11$ versus frequency for the proposed bowtie array (Antenna 4)

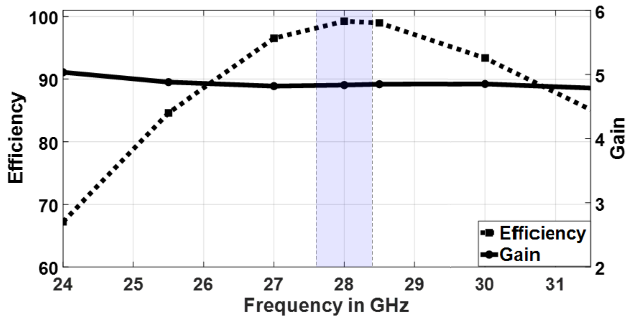

Fig. 16 Efficiency and gain for the proposed array (Antenna 4)

and efficiently and perform multitask without any internal and external interferences. The overall performance at all investigated frequency bands for the proposed antenna system is shown in Fig. 17 for comparison purposes.

6 Conclusion

With the rapid development of the application that requires high data rates and wide bandwidth, it becomes highly demanded to design an antenna system that can cope with these requirements efficiently. Thus, in this work, a new antenna system is proposed that offers multi-band performance and operates at different frequency bands covering various communication systems. The covered communication systems include UMTS, LTE, WLAN, sub-6 5G, and mmW 5G applications. Four isolated antenna components were designed on a single substrate where each one operates at a different frequency band. The results showed that all of these antenna components work perfectly in terms of impedance matching, radiation pattern, gain, and efficiency. All of the proposed antennas have shown reflection characteristics ($S11$) below −20 dB at the frequency of interest and a radiation efficiency reached above 95% in all cases with a minimum peak gain of 4 dBi.

The designed antennas are operating at different frequency bands with relatively narrow bandwidth, thus, there is no probability for the interference to occur when all

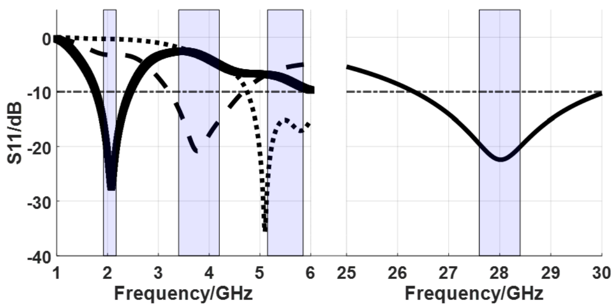

Fig. 17 $S11$ versus frequency for the proposed antennas system showing the antenna performance at each investigated band

antennas are working simultaneously. On the other hand, the designed antennas were optimized to exhibit higher gain and efficiency at the frequency of interest. Hence, most of the antennas have achieved this goal, while in few cases (i.e. Antenna 3) the gain at 5.5 GHz was a bit lower than that at 6 GHz, but still acceptable. This can be further investigated and optimized, but altering the antenna structure could lead to a change in other antenna characteristics. Thus, this trade off should be looked at carefully. Integrating such antenna systems in the future smartphones handsets will achieve better quality communications and will encourage the manufacturer to add more tasks to the device especially with the enormous growth of IoT techniques.

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