Multi/Broad-Band Phased Array Enabling Capacity and Physical-Layer Security in Cyberspace Mobile Communications for 5G and Beyond

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Abstract—**Broadband/multiband phased array antennas with wide-scan and smart beam-steering are desirable to meet the capacity and security requirements of 5G and beyond. This paper discusses the characteristics of a new beam-steerable phased array design having broadband/multiband function for 5G and beyond communications. The discussion is focused on smartphones, due to their small size and complexity. The design procedure is straightforward and accomplished on a mainboard of future smart handheld devices. The introduced phased array design involves eight Yagi-dipole resonators with a 1×8 linear form. The resonators have small sizes with discrete feedings. For -10 dB, the design represents dual broad bands including 22-33 GHz and 38-65 GHz covering multiple bands in the 5G and beyond spectrums.**

Keywords— 5G, broadband antenna, multi-resonator antenna, high capacity, physical layer security, phased array.

I. Introduction

In future networks (5G and 6G), the key role of millimeter-wave (mm-Wave) is its ability to cover multiple smart devices to demonstrate broadband wireless service [1-2]. As the demand for mobile data and smartphone usage continues to surge, wireless service providers are grappling with unprecedented challenges in their efforts to tackle a worldwide bandwidth limitation [3-4]. Since antennas are key components, these changes have a direct impact on their design. Therefore, the development of wireless communication has also brought about new design approaches and requirements for antennas [6-8].

The utilization of phased array antennas offers a multitude of benefits in terms of capacity enhancement. By dynamically adjusting the direction of the signal beam, these antennas can efficiently manage and distribute network resources, enabling higher data rates and accommodating a larger number of connected devices. This capacity expansion is vital in meeting the ever-growing demand for mobile data and supporting the diverse range of applications and services in cyberspace [9-10]. In addition to capacity enhancement, phased array antennas contribute significantly to enhancing the physical-layer security of mobile communications. Their beamforming capabilities provide a means to precisely target and direct the signal, thereby reducing the vulnerability to eavesdropping and interference. By focusing the transmission toward the intended receiver while minimizing signal leakage in other directions, these antennas enhance the confidentiality and integrity of communication channels. Therefore, future wireless systems require phased arrays with broad bandwidth and smart radiation since they enhance radiation and connectivity [12-14].

Beam-steerable antennas have revolutionized wireless communication, charting a new course for 5G and 6G applications. These antennas offer a myriad of benefits that make them highly sought-after in the field. With their ability to dynamically adjust the direction of the signal beam, beam-steerable antennas provide low latency, enabling near-instantaneous data transmission. Additionally, they offer higher data rates, facilitating faster and more efficient communication between devices. Moreover, their superior system stability ensures reliable connectivity, even in challenging environments. These remarkable characteristics position the millimeter-wave phased array antenna system as a promising contender for the future of wireless communication systems, paving the way for exciting advancements in the realm of connectivity. For this purpure, small broadband resonators could be arranged in linear/planar phased array configurations. Moreover, end-fire arrays are more suitable for achieving full coverage than typical antennas including patch, monopole, or slot antennas [15-18].

Beam-steerable arrays with miniaturized resonators and broad impedance bandwidth are desired not only in managing high data rates and capacity but also in ensuring physical layer security for future 5G networks and beyond. It can be challenging, however, to design a compact array with a small clearance that is responsive to multiple frequency bands with low latency and wide impedance bandwidth. Here, we present a miniaturized, super wideband phased array with end-fire beams that can be employed in future handheld platforms and support several bands with good protentional in enabling capacity and physical-layer security in future communications.

II. Design Details

Figure 1 plots how the suggested phased array is configured on a smartphone board with Yagi-dipole resonators. Yagi-dipole elements present a compelling solution for mm-wave applications. Their ability to achieve high gain, compact form factor, and favourable radiation characteristics make them an attractive choice for realizing efficient and reliable mm-wave communication systems. Additionally, the inherent directional nature of Yagi-dipole antennas enhances their resistance to multipath fading, making them suitable for reliable and robust communication in mm-wave scenarios. With the growing importance of mm-wave frequencies in future wireless technologies, Yagi-dipole antennas play a significant role in enabling high-performance and high-capacity mm-wave communication links [19-20]. As seen, the suggested array involves Yagi-dipole resonators with low sizes and a 1×8 form (with d= 5.35 mm) at the mainboard containing 1 mm RT5880 Rogers material. Table. I listed the values of the suggested array parameters.

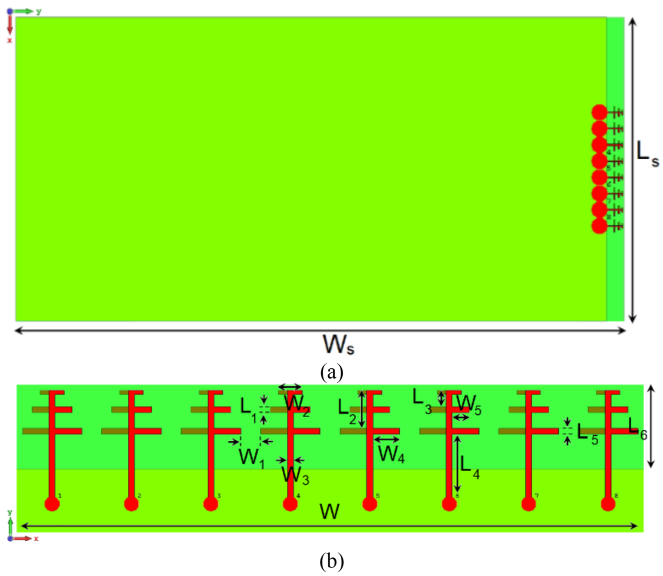

Fig. 1. (a) The suggested 5G mobile-phone antenna configuration and (b) its phased array schematic.

TABLE. I PARAMETER VALUES IN MILLIMETER (MM)

Param.	W_S	L_S	W	L	W_1	L_1	W_2	L_2
(mm)	150	75	31	4.25	1.5	0.3	1.2	1.9
Param.	W_3	L_3	W_4	L_4	W_5	L_5	h_S	L_6
(mm)	0.8	0.3	1.35	3.5	0.85	0.3	0.3	4

III. FUNDAMENTAL CHARACTERISTICS

The S-parameters of the suggested phased array design have been depicted in Fig. 2 and show the bandwidth and mutual coupling properties. As shown, the design offers coverage of two broad bands including 22-33 GHz and 38-65 GHz which can support multiple bands such as 28, 38, 45, and 60 GHz in the 5G and beyond 5G spectrums. Additionally, the resonators offer low mutual couplings of less than -10 dB over the broad/multi-bandwidth of the suggested array. CST Studio 2020 software has been used to simulate the investigated antenna design [21].

The surface currents of the single Yagi-dipole element at its selected frequency resonances (including 24, 32, and 57 GHz) have been studied and represented in Fig. 3. It can be clearly observed that different parts of the suggested Yagi-dipole and its rectangular arms are actively involved in generating the resonances and improving the bandwidth [22-24]. As shown, the largest area coverage with high current densities is representing the lower band and vice versa. Furthermore, the antenna resonators show high-efficiency performance over its broad bandwidth [25].

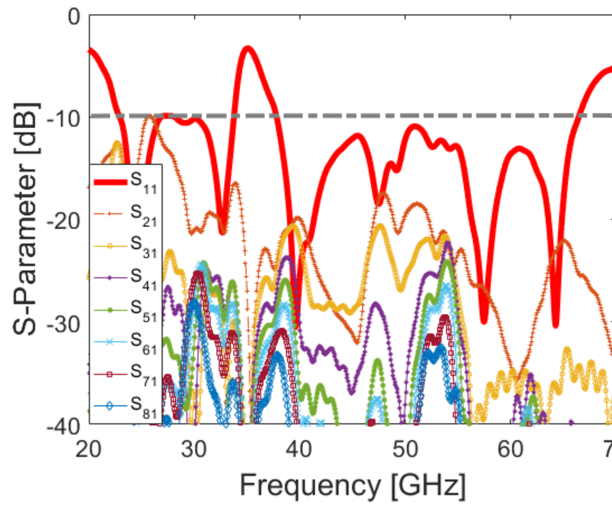

Fig. 2. Simulated scattering parameters.

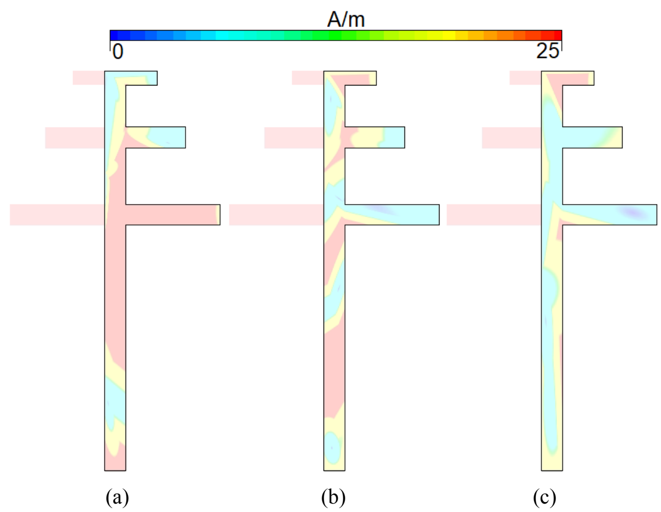

Fig. 3. Current densities at (a) 24, (b) 32, and (c) 65 GHz.

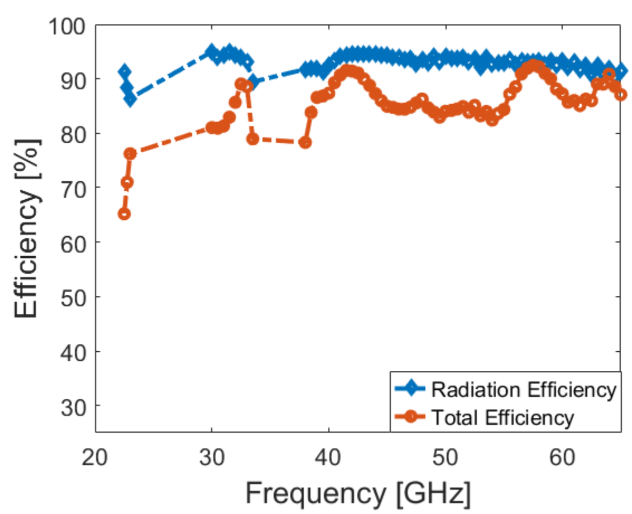

Fig. 4. Efficiencies of a single Yagi-dipole.

As illustrated in Fig. 4. more than 90% radiation efficiencies and 75% total efficiencies are observed over the operation band of the designed array which is quite satisfactory. For various frequencies, the main radiations from the array beams (at 0°) are shown in Fig. 5. As shown, highly satisfactory radiations which support half radiation coverage with end-fire modes and constant performance have been discovered for different frequencies. Another set of the suggested array can be deployed at the bottom side of the board for full coverage purposes [26-27].

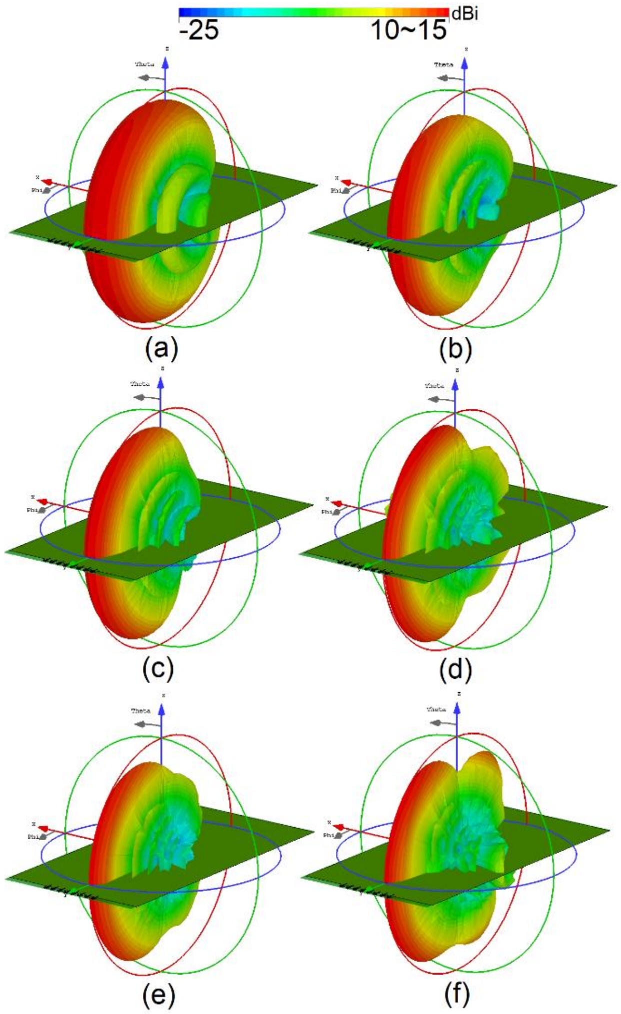

Fig. 5. Main radiations of the suggested super-wideband phased array at (a) 25, (b) 32, (c) 37, (d) 45, (e) 55, and (f) 65 GHz.

The gain-levels of the single Yagi-dipole and its linear array and the results have been conducted and shown in Fig. 5. The single Yagi-dipole element exhibits 3.5~6.5 dBi gain, while its array shows 10-15 dBi. 3D beam-steering at 30 GHz is represented in Fig. 7. A broad scanning range of 0°-60° is evident in the investigated array. As well as this, effective end-fire radiations at various angles have been discovered that offer several advantages such as effective interference mitigation, improved signal quality and increased capacity. In addition, by steering the beam towards the desired direction, the transmission power can be focused, reducing power wastage in unnecessary directions. [28-30].

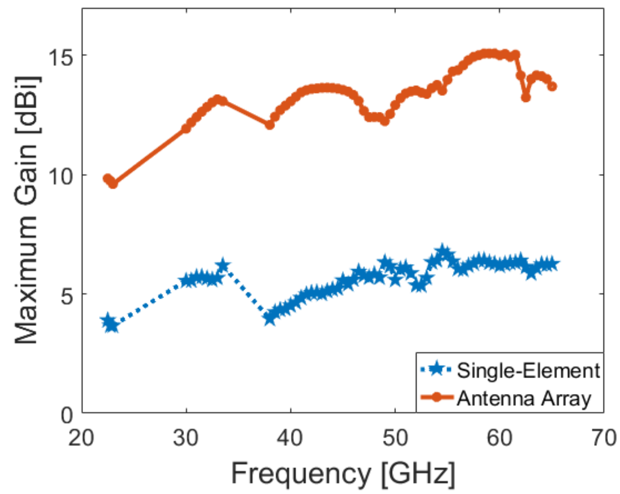

Fig. 6. Gains of the Yagi-element and its linear array configuration.

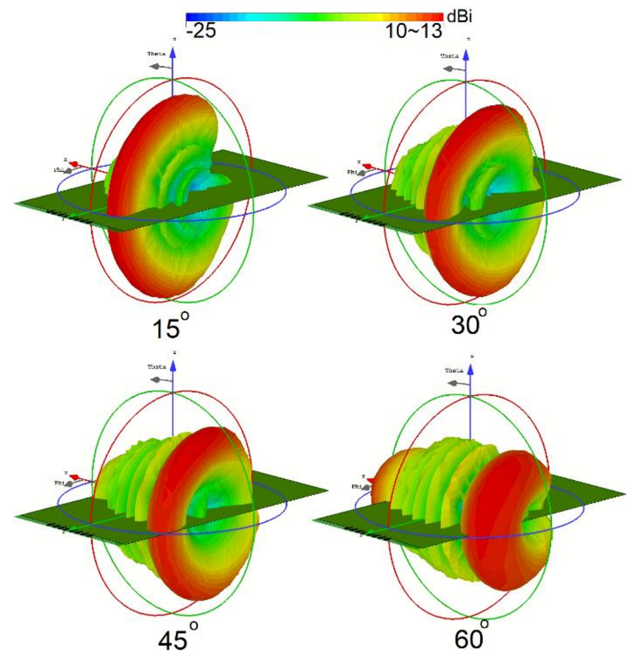

Fig. 7. 3D beam steering at 30 GHz.

IV. Conclusion

As the deployment of 5G networks progresses and the anticipation for future advancements grows, the integration of phased array antennas in mobile communications systems becomes increasingly crucial. Their unique capabilities in enhancing capacity, improving physical-layer security, and enabling robust and efficient communication make them an indispensable technology for the development of cyberspace mobile communications in the era of 5G and beyond. In this study, a new broadband/multiband phased array containing low-profile eight Yagi-dipole resonators is reported for enabling capacity and physical-layer security. The array supports multiple bands such as 26, 28, 38, 45, and 60 GHz in the 5G and beyond 5G spectrums. The investigation of scattering parameters, radiation steering, the levels of gain and efficiencies showed sufficient results with the design.

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REFERENCES

[1] T.S. Rappaport, *et al.,* "Millimeter wave mobile communications for 5G cellular: It will work!," *IEEE Access*, vol.1, pp. 335-349, May 2013.

[2] Osseiran, *et al.,* "Scenarios for 5G mobile and wireless communications: the vision of the METIS project," *IEEE Commun. Mag.*, vol. 52, pp.26-35, 2014.

[3] S. A. Khaleel, *et al.,* "MTM-Inspired Graphene-Based THz MIMO Antenna Configurations Using Characteristic Mode Analysis for 6G/IoT Applications," *Electronics*, vol. 11, no. 14, p. 2152, Jul. 2022.

[4] S. Rajagopal, S. Abu-Surra, Z. Pi and F. Khan, "Antenna array design for multi-gbps mmwave mobile broadband communication," *Proc. IEEE GLOBECOM'2011*, Houston, Texas, USA, pp.1-6, 2011.

[5] N. Ojaroudiparchin, et al., "Wide-scan phased array antenna fed by coaxto-microstriplines for 5G cell phones," *MIKON*, Poland, 2016.

[6] M. E. Munir et al., "A New mm-Wave Antenna Array with Wideband Characteristics for Next Generation Communication Systems," *Electronics*, vol. 11, no. 10, p. 1560, May 2022.

[7] N. O. Parchin, "Low-profile air-filled antenna for next generation wireless systems," *Wirel. Pers. Commun.,* vol. 97, pp. 3293–3300, 2017.

[8] Y. AI-Yasir, et al., "New pattern reconfigurable circular disk antenna using Two PIN diodes for WiMax/WiFi (IEEE 802.11a) applications," *SMACD*, 2019, pp. 53-56.

[9] C.P. Narayan, "*Antennas and propagation*," Technical Publications, 2007.

[10] N. Yang, L. Wang, G. Geraci, M. Elkashlan, J. Yuan, and M. Di Renzo, "Safeguarding 5G wireless communication networks using physical layer security," *IEEE Commun. Mag.*, vol. 53, no. 4, Apr. 2015.

[11] N. Ojaroudi, Sh. Amiri, and F. Geran, "Reconfigurable monopole antenna with controllable band-notched performance for UWB communications," *TELFOR 2012*, November 2012, Belgrade, Serbia.

[12] J. Zhang, X. Ge, Q. Li, M. Guizani, and Y. Zhang, "5G Millimeter-Wave Antenna Array: Design and Challenges," *IEEE Wireless Communications*, vol. 24, no. 2, pp. 106-112, 2017.

[13] R. Rodriguez-Cano, S. Zhang, K. Zhao, and G. F. Pedersen, "Mm-wave beam-steerable endfire array embedded in a slotted metal-frame LTE antenna," *IEEE Trans. Antennas Propag.*, vol. 68, no. 5, pp. 3685–3694, May 2020.

[14] Q. Chen, *et al.,* "Design considerations for millimeter wave antennas within a chip package," *IEEE International Workshop on Anticounterfeiting, Security, Identification*, 16-18 April 2007, Xiamen, China.

[15] Stanojev and A. Yener, "Improving Secrecy Rate via Spectrum Leasing for Friendly Jamming," *IEEE Trans. on Wireless Comm.,* Vol. 12, No. 1, pp. 134-145, Jan. 2013.

[16] N. O. Parchin, *et al.,* "A planar dual-polarized phased array with broad bandwidth and quasi-endfire radiation for 5G mobile handsets," IEEE Trans. Antennas Propag., vol. 69, pp. 6410-6419, 2021.

[17] W. Hong, *et al.,* "Design and analysis of a low-profile 28 GHz beam steering antenna solution for future 5G cellular applications," IEEE international microwave symposium, 1-6 June 2014, Florida, USA.

[18] J. J. H. Wang, "Wideband wide-scan millimeter-wave phased arrays for enhanced security/privacy and performance in 5G mobile wireless," USNC/URSI National Radio Science Meeting, 2017, pp. 1471-1472.

[19] *CST Microwave Studio*, ver. 2021, CST, Framingham, MA, USA, 2021.

[20] S.-J. Park, D.-H. Shin, and S.-O. Park, ''Low side-lobe substrate integrated-waveguide antenna array using broadband unequal feeding network for millimeter-wave handset device,'' IEEE Trans. Antennas Propag., vol. 64, no. 3, pp. 923–932, Mar. 2016.

[21] N. Ojaroudi Parchin, *et al.,* ''A new CPW-fed diversity antenna for MIMO 5G smartphones,'' *Electronics*, vol. 9, no. 2, p. 261, Feb. 2020.

[22] N. Ojaroudi, "Application of protruded strip resonators to design an UWB slot antenna with WLAN band-notched characteristic," *Progress in Electromagnetics Research C*, vol. 47, 111-117, 2014.

[23] Y. I. A. Al-Yasir, *et al.,* "A New Polarization-Reconfigurable Antenna for 5G Wireless Communications," *Broadband Communications, Networks, and Systems*, Faro, Portugal, 2019, pp. 431-437.

[24] Y. S. Faouri, *et al.,* "A Novel Meander Bowtie-Shaped Antenna with Multi-Resonant and Rejection Bands for Modern 5G Communications," *Electronics*, vol. 11, no. 5, p. 821, Mar. 2022.

[25] S. Ahmad, *et al.,* "A Jug-Shaped CPW-Fed Ultra-Wideband Printed Monopole Antenna for Wireless Communications Networks," *Applied Sciences*, vol. 12, no. 2, p. 821, Jan. 2022.

[26] Y. Al-Yasir, *et al.,* "Green and Highly Efficient MIMO Transceiver System for 5G Heterogenous Networks," IEEE Trans. Green Commun. Netw. 2022.

[27] M. A. Abdelgader, R. Jonathan, E. Issa, and T. Antonio, "Millimeter Wave Antenna Design for 5G Applications," *in Optical and Wireless Convergence for 5G Networks: IEEE*, 2019, pp. 139-156.

[28] N. O. Parchin*, et al.,* "Small-Size Tapered Slot Antenna (TSA) Design for use in 5G Phased Array Applications," *Applied Computational Electromagnetics Society Journal*, vol. 32, no. 3, pp. 193–202, Mar. 2017.

[29] S. Ahmad, *et al.*, "Design of a Tri-Band Wearable Antenna for MillimeterWave 5G Applications," Sensors, vol. 22, no. 20, p. 8012, Oct. 2022.

[30] N. O. Parchin, *et al.*, "UWB mm-wave antenna array with quasi pmnidirectional beams for 5G handheld devices", *ICUWB 2016*, October 2016, Nanjing, China.