Open Loop Resonator Based Filtering Antenna for 5g Mimo Base Station

Suleiman Babale Aliyu, Kim Geok Tan,
Mohamed Abdelfattah Morsi Abdelkarim Marei and
Sharul Kamal Abdul Rahim

October 10, 2023

OPEN LOOP RESONATOR BASED FILTERING ANTENNA FOR 5G MIMO BASE STATION

Suleiman Aliyu Babale

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia

Department of Electrical Engineering, Bayero University, Kano - Nigeria
sababale.ele@buk.edu.ng

Tan Kim Geok

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia.

kgtan@mmu.edu.my

Mohamed Abdelfattah Morsi Abdelkarim Marei

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia.

1151303381@student.mmu.edu.my

Sharul Kamal Abdul Rahim

Wireless Communication Centre, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia

sharulkamal@fke.utm.my

Abstract— The study introduces a filtering antenna (filtenna) designed to operate at 3.5 GHz for 5G MIMO base stations. This filtenna combines a ring resonator and a diamond-shaped patch antenna optimized for this frequency, exhibiting a single filtering pole with a gain of 5.98 dBi as a single element. A 1×2 array of filtennas was created using a 3.5 GHz microstrip power divider, resulting in an in-band gain of 8.07 dBi and improved performance compared to a single filtenna. The study demonstrated that the filtering antenna effectively operates at the desired frequency and can reject interference from nearby antennas, making it suitable for sub-6 GHz 5G communications.

Keywords— *filtering antenna, ring resonator, MIMO antenna, 5G communications*

I. INTRODUCTION

A filtering antenna is a type of antenna that incorporates a filtering function to suppress interference and achieve specific frequency response characteristics. It can radiate signals while simultaneously suppressing unwanted signals or frequencies. This is contrary to the operations of classical antennas presented in [1], [2]. Several papers have proposed different designs for filtering antennas. One paper presents a novel broadband dual-polarized filtering patch antenna array using low-temperature co-fired ceramic (LTCC) process for 5G millimeter-wave applications [3]. Another paper describes a metamaterial inspired dual-band filtering antenna that covers both the WLAN 2.4 GHz and WiMax 3.5 GHz bands [4]. A different paper introduces an antenna element with a filtering function, which can radiate signals and suppress interference simultaneously [5]. Liang et al proposes a filtering patch antenna based on parasitic patches, which achieves a quasi-elliptic boresight gain response [6].

Also, another paper presents a planar filtering patch antenna inspired by a bandpass filter prototype, which achieves good filtering response with radiation nulls on the sides of the passband [7]. In another paper, the author proposes a tunable quasi-reflectionless filtering antenna for multicarrier transceiver applications. It combines a reflective microstrip bandstop filter with a radiating patch antenna in a complementary-duplexer arrangement, distributing spectrum resources to different elements for multicarrier base stations. The prototype exhibits a fractional bandwidth of 3.2%, tuning from 3.6 to 4.1 GHz in each band, and a maximum gain of 5.5 dBi [8].

A patch antenna array without any filtering functionality was presented in [9]. As against the non-filtering property, a dual-polarized filtering antenna for 5G mm-Wave phased arrays was presented in [10]. It integrates filtering structures with radiating patches and a feed network to achieve bandpass filtering and suppress out-of-band radiation. Operating in n257 and n258 mm-Wave bands, the antenna shows a -10 dB impedance bandwidth from 24.25 to 29.5 GHz. Gain remains stable at 5-6 dBi, and isolation and cross-polar discrimination stay better than 20 dB across the frequency range. Chun et al introduce a compact multiplexing filtering antenna for four frequency bands. It features one shared radiator and four ports, enabling concurrent support for four transmission channels. Measurement results agree with simulations, revealing channels spanning 4.5-4.8 GHz, 5.1-5.3 GHz, 5.85-6.3 GHz, and 6.4-6.6 GHz with over 25 dB isolation between them. The antenna maintains consistent radiation patterns and polarization across the four bands, suitable for multiservice wireless communication systems [11].

In this paper, a filtering antenna for a 5G MIMO base station has been proposed. The antenna consists of a diamond-shaped patch integrated with an open-loop resonator. Both were designed to operate at a center frequency of 3.5 GHz for a small indoor wireless application.

II. ANTENNA MODEL

The mathematical model to be used in designing the Microstrip patch antennas typically includes parameters such as the antenna's dimensions, resonant frequency, substrate material, and feed point location. While offering a basic understanding of the antenna's behavior and performance, the model. It serves as a useful tool for initial design decisions and was adopted according to the design criteria highlighted in [12], and [13].

$$W = \frac{v_o}{2f_c}\sqrt{\frac{2}{1+\varepsilon_r}} \quad (1)$$

$$\varepsilon_{eff} = \frac{1+\varepsilon_r}{2} + \frac{\varepsilon_r - 1}{2}\,[1+\frac{12h}{W}]^{-1/2} \quad (2)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-o.258)(\frac{W}{h}+0.8)} \quad (3)$$

$$\Delta L_{eff} = L + 2\Delta L \quad (4)$$

$$L = \frac{v_o}{2f_c\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (5)$$

Where W represents the width of the patch element, fc stands for the center frequency, h corresponds to the substrate material's height, L denotes the effective length of the patch element, ΔL accounts for the alteration in length due to fringing effects, ε_r indicates the dielectric constant of the substrate material, ε_{eff} reflects the effective dielectric constant, Vo symbolizes the velocity of light, and $L_{eff,}$ signifies the patch's effective length.

Based on the above model, a diamond-shaped patch antenna operating at 3.5 GHz was designed and optimized. **Figure 1** depicts the top view geometry of the diamond-shaped antenna. The antenna was designed and simulated using a Rogers RT6002 substrate having a thickness of 1.52 millimeters, a relative permittivity of 2.94, and a loss tangent of 0.0012.

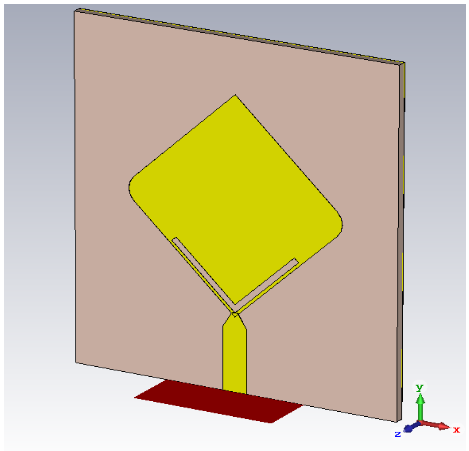


Figure 1: The layout of the diamond-shaped patch antenna

The radiator's shape was created with a diamond shape, with a slit situated just at the feeding point, which modified the surface current of the antenna and maintained in providing a good impedance matching. The antenna is fed by a 50-ohm microstrip feeding line.

III. OPEN LOP RESONATOR MODEL

To realize a filtering antenna, An Open loop resonator (OLR) designed to operate at a 3.5 GHz for the purpose of integration as OLR was found to have good filtering properties [14], [15] with minimum insertion loss. The geometry of the OLR is shown in **Figure 2**.

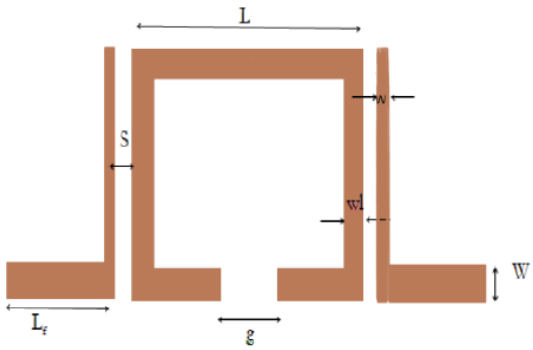


Figure 2: Geometry of the OLR

The OLR can be designed for any frequency f according to [16]:

$$f = \frac{C}{2L_{eff}\sqrt{\varepsilon_{eff}}} \quad (6)$$

$$L_{eff} = 4L - g - 4w_l = \frac{\lambda_g}{2} \quad (7)$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + \frac{12h}{w_f}\right]^{-0.5} \quad (8)$$

Where L_{ef} stands for the effective length of the Optically Loaded Resonator (OLR), L represents the OLR's length, L_f corresponds to the feed line's length, w denotes the width of the feed line, wl signifies the width of the OLR, h indicates the substrate's height, g represents the gap within the OLR, S denotes the spacing between the OLR and the feed line, ε is the dielectric constant of the substrate, and ε_{eff} reflects the system's effective dielectric constant.

Based on the parameters of the substrate given in datasheet, an OLR was designed, and its layout and the results are shown in **Figure 3**.

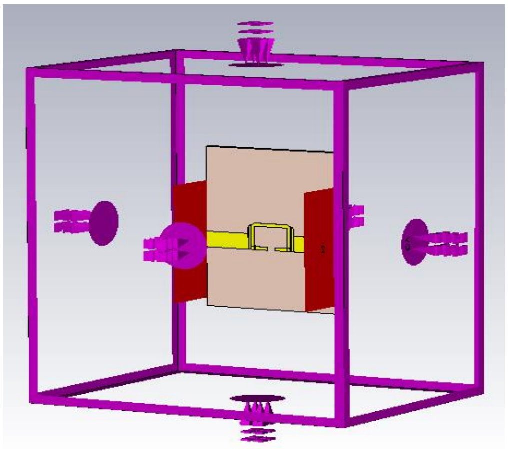
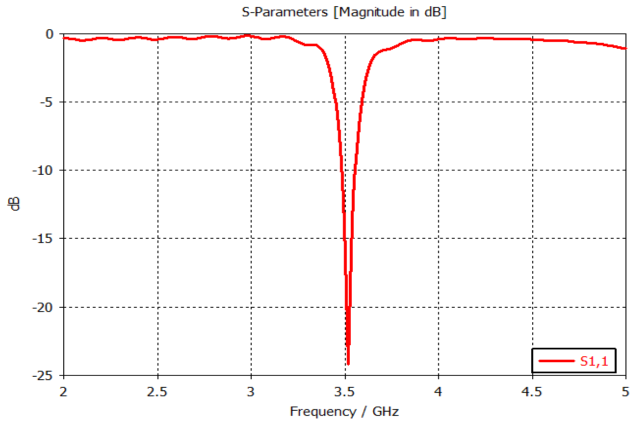


Figure 3: Layout of the open loop resonator filter

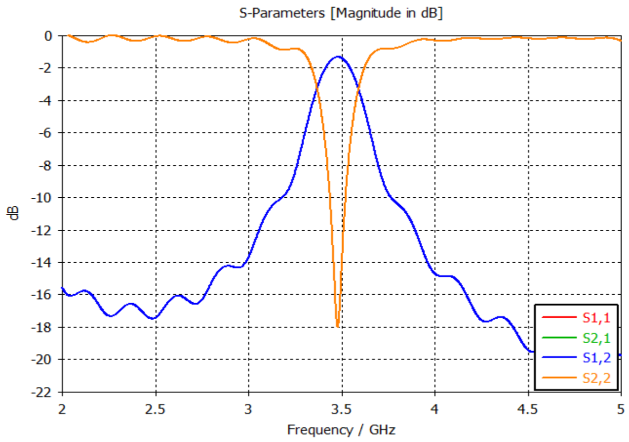
IV. RESULT AND DISCUSSIONS

A. Antenna and the OLR

After careful design of the antenna and the open loop resonator from the model of equation (1) to (8), A commercially available CST Microwave Studio 2023® was used to simulate and optimize both the antenna and the resonator separately. **Figure 4**(a) shows the s-parameter result of the diamond shaped antenna whereas, the s-parameter of the OLR was depicted in **Figure 4**(b).



(a)

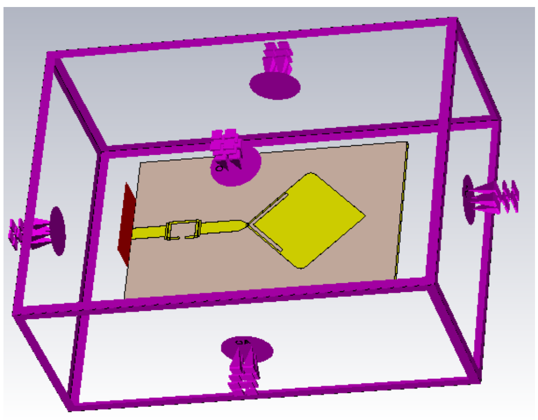


(b)

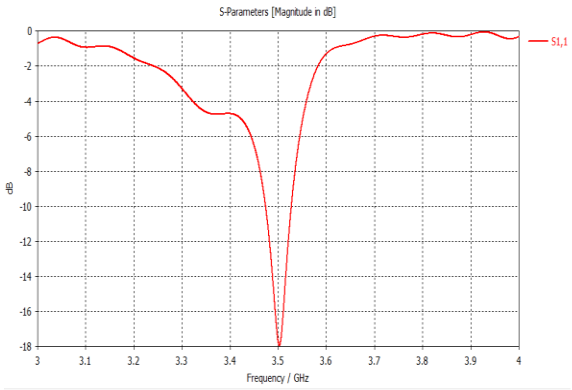
Figure 4: S-parameter results; (a) S11 for the diamond-shaped antenna; (b) S11 for the open loop resonator filter.

B. Filtering Antenna

After a separate design of the antenna and the OLR, the two structures were coupled via a matched 50Ω transmission line circuit and the resultant structure, filtenna was obtained. Overall result sometime does not perfectly coincide with the individual designs due to losses due to the coupling. Layout of the final structure after optimization and the s- parameter result was shown in **Figure 5**.



(a)

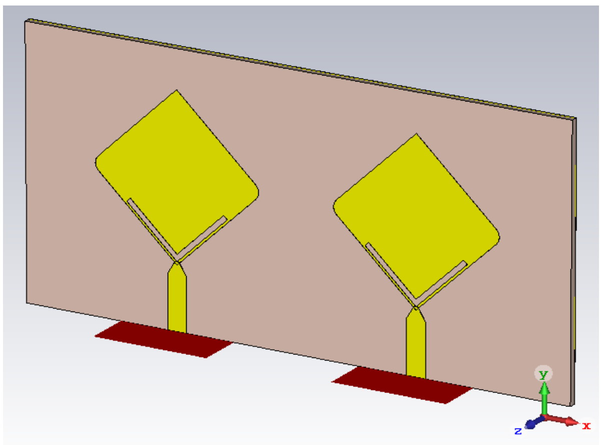


(b)

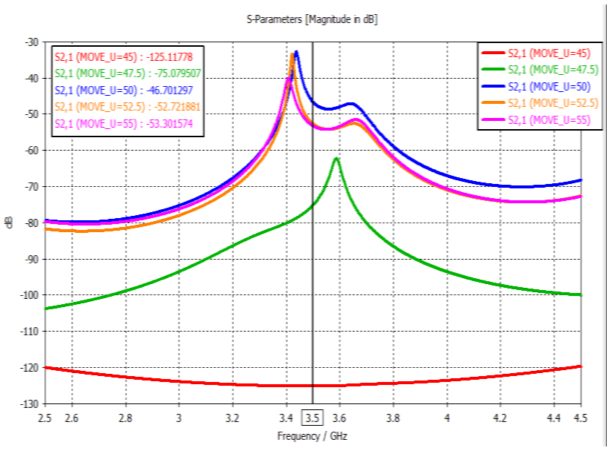
Figure 5: Diamond-shaped Filtenna: (a) Layout, (b) S-parameter.

C. MIMO Antenna

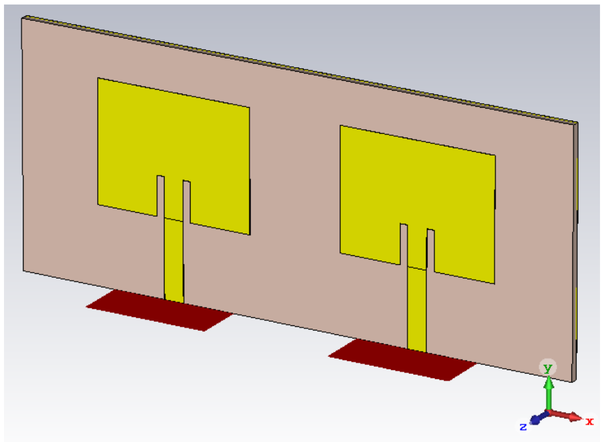
Based on the results obtained and shown in **Figure 5**, the filtering antenna performed very well at the intended frequency of operation. To prove its workability, a MIMO antenna was formed with the proposed design and was simulated for various inter-element distance around the guided wavelength of the filtenna (from 45mm to 55mm). The layout and the transmission coefficient of the MIMO S21 was shown in **Figure 6**(a) and (b).



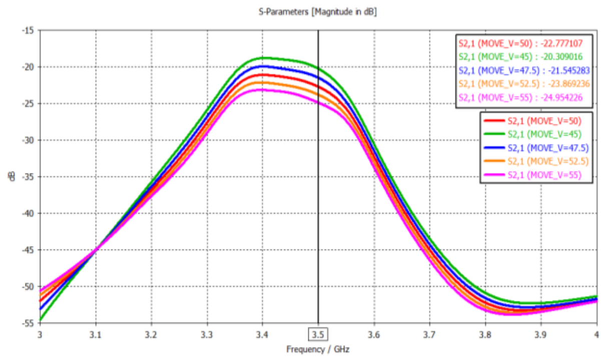
(a)



(b)



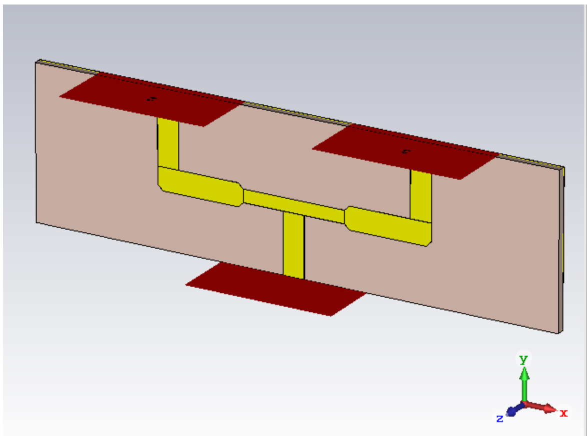
(c)



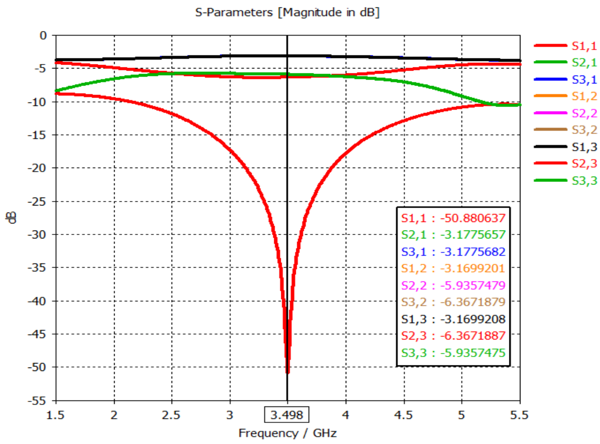
(d)

Figure 6: MIMO Antenna Showing Isolations at various separations: (a) Layout of the proposed 1 x 2 MIMO Antenna, (b) S-parameter of the proposed MIMO, (c) Layout of conventional 1 x 2 MIMO Antenna, (d) S-parameter of the conventional 1 x 2 MIMO Antenna.

On the other hand, a conventional microstrip patch antenna was designed, and a MIMO antenna formed at the same inter-element distance. The layout and the result of the conventional MIMO was shown in **Figure 6** (c) and (d). From the two results in **Figure 6**. It can clearly be seen that; the proposed filtering antenna works well as assumed. The transmission coefficient at the various distances were far less than those obtained from the conventional design. This proved that the filtering antenna is capable of rejecting any interference from neighboring antennas radiating within its vicinity. When this was established, a power divider was designed at the same frequency and tested. Its geometry and result were shown in **Figure 7**.



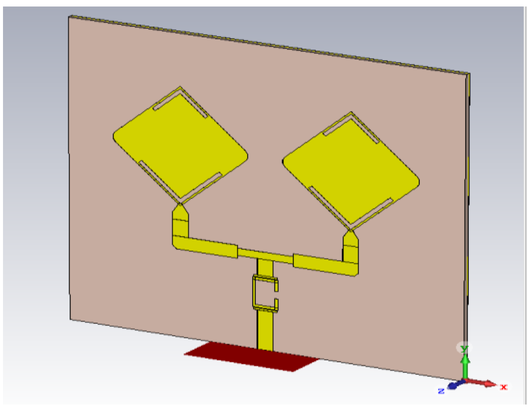
(a)



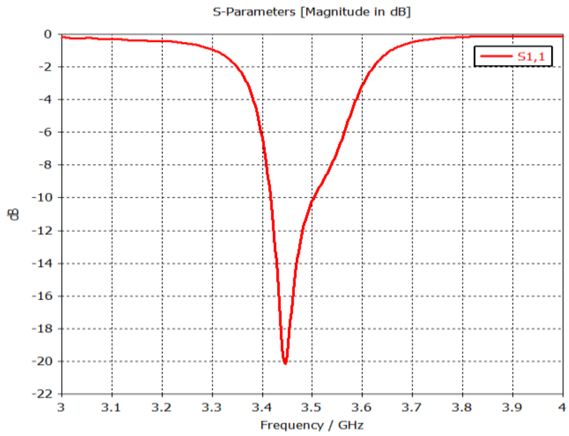
(b)

Figure 7: 1 x 2 Power Divider: (a) Layout, (b) S-parameter

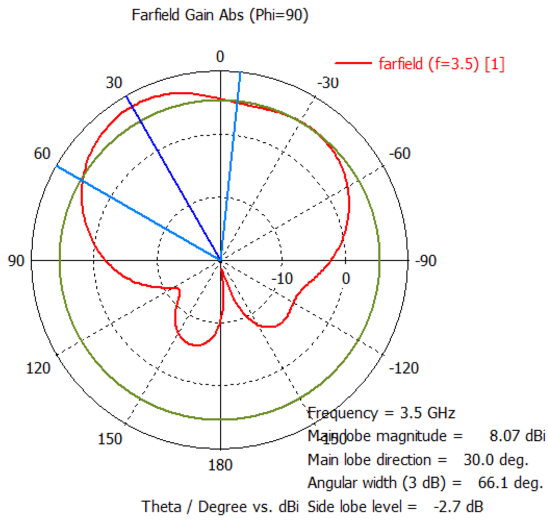
From the result of the power divider, it can be seen that it was able to divide the power equally at the output ports. After achieving the equal power division, a 4-way power divider was then formed from the 2-way power divider. The filtering antenna was then integrated on the 4-way power divider and the resultant gives a 1x4 filtering antenna array operating at 3.5 GHz. The layout and other results of the final structure after optimizations were shown in **Figure 8**.



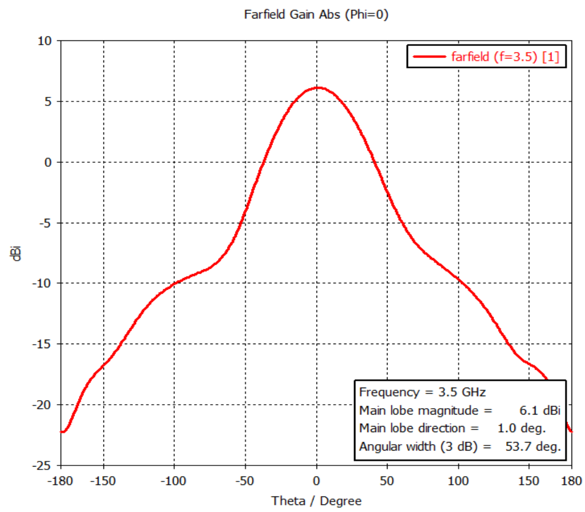
(a)



(b)



(c)



(d)

Figure 8: 1 x 2 Filtenna Array. (a) Layout, (b) S-parameter, (c) 3D Radiation Pattern, (d) cartesian Radiation Pattern showing the Gain Plot.

V. CONCLUSION

This article introduced an innovative filtering antenna (filtenna) designed for optimal performance at 3.5 GHz, catering to the requirements of 5G MIMO base stations. By integrating a ring resonator and a standard diamond-shaped patch antenna at the same frequency, a cohesive design was achieved. The single element filtenna showcased impressive filtering capabilities, featuring a singular filtering pole and a gain of 5.98 dBi. Subsequently, the development of a 3.5 GHz microstrip power divider facilitated the creation of a 1×2 array of the filtenna, further emphasizing its potential for practical deployment. The filtering antenna array, boasting a gain of 8.07 dBi and two resonant poles, outperformed the individual filtenna unit, substantiating the concept's scalability and effectiveness. The successful operation of the filtering antenna at the intended frequency was evident, offering a promising solution for 5G communication needs. Additionally, the MIMO antenna derived from this concept exhibited robust performance characteristics when tested for various inter-element distances, showcasing remarkable interference rejection with a worst-case transmission coefficient value exceeding that of conventional antennas. This stresses the filtering antenna's suitability for sub-6 GHz fifth generation (5G) communications, presenting a valuable contribution to the advancement of wireless connectivity technologies.

VI. REFERENCES

[1] S. I. Orakwue, R. Ngah, O. Elija, and S. A. Babale, "Bandwidth Enhancement of Circular Polarized Microstrip Antenna at 2.4 GHz for WLAN Applications," *Adv Sci Lett*, vol. 24, no. 6, pp. 3933–3936, Jun. 2018, doi: 10.1166/asl.2018.11514.

[2] S. A. Babale, M. K. Ishfaq, A. Raza, J. Nasir, A. Fayyaz, and U. Ijaz, "Compact Multibeam Array with Miniaturized Butler Matrix for 5G Applications," *Computers, Materials & Continua*, vol. 72, no. 1, pp. 925–937, 2022, doi: 10.32604/cmc.2022.024711.

[3] Y. Zhang, W. Yang, Q. Xue, J. Huang, and W. Che, "Broadband Dual-Polarized Differential-Fed Filtering Antenna Array for 5G Millimeter-Wave Applications," *IEEE Trans Antennas Propag*, vol. 70, no. 3, pp. 1989–1998, Mar. 2022, doi: 10.1109/TAP.2021.3118800.

[4] R. Chakraborty, C. Goswami, and R. Ghatak, "Metamaterial Inspired Filtering Antenna for Dual Band Applications," in *2021 2nd International Conference on Range Technology (ICORT)*, IEEE, Aug. 2021, pp. 1–4. doi: 10.1109/ICORT52730.2021.9581808.

[5] J. B. Jadhav and P. J. Deore, "Filtering antenna with radiation and filtering functions for wireless applications," *Journal of Electrical Systems and Information Technology*, vol. 4, no. 1, pp. 125–134, May 2017, doi: 10.1016/j.jesit.2016.10.007.

[6] G.-Z. Liang and F.-C. Chen, "High Selectivity Filtering Patch Antenna Using Parasitic Patches," in *2021 IEEE MTT-S International Wireless Symposium (IWS)*, IEEE, May 2021, pp. 1–3. doi: 10.1109/IWS52775.2021.9499474.

[7] S. Ji and Y. Dong, "Bandpass Filter Inspired Filtering Patch Antenna," in *2021 IEEE MTT-S International Wireless Symposium (IWS)*, IEEE, May 2021, pp. 1–3. doi: 10.1109/IWS52775.2021.9499492.

[8] T. Liang, Y. Dong, Z. Wang, X. Chen, and H. Wang, "Quasi-Reflectionless Tunable Filtering Antenna for Multicarrier Transceiver," *IEEE Antennas Wirel Propag Lett*, vol. 20, no. 6, pp. 1053–1057, Jun. 2021, doi: 10.1109/LAWP.2021.3070806.

[9] U. Musa, S. Babani, S. A. Babale, A. S. Ali, Z. Yunusa, and S. H. Lawan, "Bandwidth enhancement of millimeter-wave microstrip patch antenna array for 5G mobile communication networks," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 4, pp. 2203–2211, Aug. 2023, doi: 10.11591/eei.v12i4.4680.

[10] Z. Siddiqui *et al.*, "Dual-Polarized Filtering Antenna for mm-Wave 5G Base Station Antenna Array," in *2021 15th European Conference on Antennas and Propagation (EuCAP)*, IEEE, Mar. 2021, pp. 1–4. doi: 10.23919/EuCAP51087.2021.9411318.

[11] C. X. Mao, L. Zhang, M. Khalily, Y. Gao, and P. Xiao, "A Multiplexing Filtering Antenna," *IEEE Trans Antennas Propag*, vol. 69, no. 8, pp. 5066–5071, Aug. 2021, doi: 10.1109/TAP.2020.3048589.

[12] U. Musa, S. Babani, S. A. Babale, S. Halliru, A. S. Ali, and Z. Yunusa, "Millimeter Wave Microstrip Patch Antenna for Next-Generation Mobile Communication Networks," in *2022 IEEE International RF and Microwave Conference (RFM)*, IEEE, Dec. 2022, pp. 1–3. doi: 10.1109/RFM56185.2022.10064918.

[13] S. A. Babale, O. Elijah, S. K. A. Rahim, and S. I. Orakwue, "Two-dimensional beam-steering phased-array utilizing 2×2 Butler matrix," in *2017 IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON)*, IEEE, Nov. 2017, pp. 245–248. doi: 10.1109/NIGERCON.2017.8281896.

[14] D. E. Senior, Xiaoyu Cheng, M. Machado, and Yong-Kyu Yoon, "Single and dual band bandpass filters using complementary split ring resonator loaded half mode substrate integrated waveguide," in *2010 IEEE Antennas and Propagation Society International Symposium*, IEEE, Jul. 2010, pp. 1–4. doi: 10.1109/APS.2010.5561779.

[15] A. H. Reja and S. N. Ahmad, “Design of Multiband Metamaterial Microwave BPFs for Microwave Wireless Applications,” 2015, pp. 179–192. doi: 10.1007/978-3-319-11218-3_18.

[16] J.-S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*. New York, USA: John Wiley & Sons, Inc., 2001. doi: 10.1002/0471221619.