A Wideband Dual-Polarized Filtering Antenna for Multi-Band Base Station Application

Xuekang Liu[1], Benito Sanz-Izquierdo[2], Haiwei Zhang[3], Steven Gao[4]
[1] (University of Kent): School of Engineering, Canterbury, UK, xl255@kent.ac.uk
[2] (University of Kent): School of Engineering, Canterbury, UK
[3] (Huawei Technologies Ltd): Shenzhen, China
[4] (Chinese University of Hong Kong): Department of Electronic Engineering, Hong Kong, China

***Abstract*—A dual-polarized filtering antenna with wide impedance bandwidth and good rejection level in n78 (3.3-3.8 GHz) and n79 (4.8- 5.0 GHz) bands is realized in this paper. By deftly exciting the inherent radiation nulls of the dual-coaxial-fed dipole antenna, good out-of-band rejection levels can be achieved in both the lower frequency band and the n79 band. Then, by replacing the ordinary dipole arms with split loop resonators, new adjustable radiation null can be obtained in the n78 band. The effective length of the split loop resonator can be changed to conveniently alter this radiation null. To confirm the design principle, a prototype of the proposed design was made and tested. The fabricated prototype achieves a wide impedance bandwidth of 52% (1.69- 2.87 GHz) which can cover all established 1.71–2.69 GHz LTE bands. Besides, the proposed antenna realizes good gain suppression levels at the n78 and n79 bands. The tested mutual coupling between its differential input ports is lower than -40 dB.**

***Index Terms*—filtering antenna, dual-polarized, base station, wideband.**

I. Introduction

As wireless communication technology advanced, more and more frequency bands were released to meet the growing demand of people. The design of antennas should not only meet the requirements of broadband, but also realize filtering characteristics to reduce the coupling between the antennas working at different frequency bands.

Some dual-polarized antennas with wide impedance bandwidths were reported in [1]-[3]. However, all of these antennas have no filtering capability. To obtain filtering response, many methods are proposed in [4]-[17]. In [4]-[7], by introducing filtering structures on feeding transmission lines, some dual-polarized antennas with good gain-suppression in unwanted frequency bands are developed. However, this method usually makes the design of the feeding structure more complicated.

In [8]-[10], parasitic structures are introduced to suppress the gain in lower or upper out-of-band. By placing a pair of crossed strips above the radiator, the gain between two desired frequency bands can be effectively suppressed [8]. In [9], by introducing four U-shaped parasitic structures around the radiator, two radiation nulls can be achieved in lower and higher out-of-band. Finally, a compact and wideband filtering antenna with dual-polarization and good gain suppression level was developed. The impedance bandwidth of this antenna is 63%.

In [13], by symmetrically loading slots on the ground plane and patch, a low profile dual-polarized filtering antenna was realized to cover an impedance bandwidth of 23%. By combining the defected ground structure, split loop resonator, parasitic loop, and differential feed structure, the antenna in [14] realizes a 56% impedance bandwidth, an excellent gain-suppression level in out-of-band, and a high isolation.

In this paper, by merging the split loop resonators into the radiator and introducing a parasitic loop, a dual-polarized filtering antenna with wide impedance bandwidth, four controllable radiation nulls is designed. The proposed antenna obtains a wide impedance bandwidth of 52% that can cover the 2/3/4G band (1.71-2.69 GHz) and good gain suppression level at the two sub-6G bands (n78:3.3-3.8 GHz and n79 4.8-5.0 GHz). To confirm the working principle of the proposed antenna, a prototype of the proposed antenna was made and tested. The tested results are in good agreement with the simulated results obtained using Ansys HFSS.

II. Dual-Polarized Filtering Antenna

A. Configuration

Detailed dimensions of the developed design are given in Fig.1. As depicted, the proposed design consists of two Rogers 4003 substrates with the thickness of 0.5mm and three metal layers. Two metal strips used to connect the inner conductors are arranged on the top layer of the substrate 1. On the bottom layer of the substrate 1, there are two pairs of dipoles and a parasitic loop. The dipole arms are connected to the reflector which is arranged on the bottom of the lower substrate through the outer conductors of the coaxial cables. The S-parameters in this paper can be obtained by:

$$S_{dd11} = (S_{1a1a} + S_{1b1b} - S_{1a1b} - S_{1b1a})/2 \quad (1)$$

$$S_{dd22} = (S_{2a2a} + S_{2b2b} - S_{2a2b} - S_{2b2a})/2 \quad (2)$$

$$S_{dd21} = (S_{2a1a} + S_{2b1b} - S_{2a1b} - S_{2b1a})/2 \quad (3)$$

$$S_{dd12} = (S_{1a2a} + S_{1b2b} - S_{1a2b} - S_{1b2a})/2 \quad (4)$$

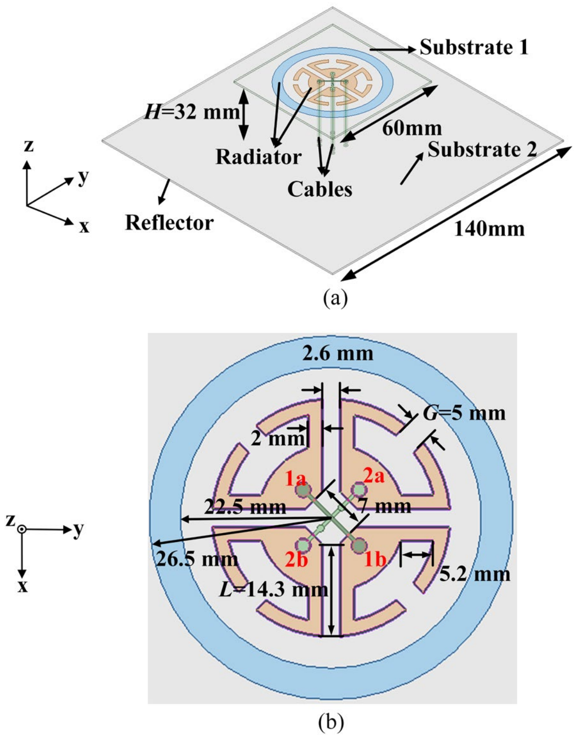


Fig. 1. The simulated antenna geometry. (a) 3D view, and (b) top view.

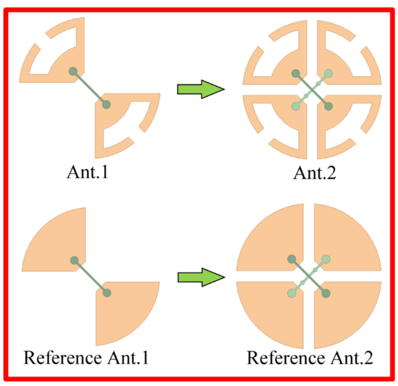


Fig. 2. Evolution of the proposed antenna.

where S_{ij} (i,j = 1a, 1b, 2a, 2b) represents the S-parameters of different ports.

B. Radiation Nulls

To interpret the design method of the presented antenna, serval reference structures are designed as shown in Fig. 2. Ant.1 and reference Ant.1 are two differentially-fed antennas with single polarization, while Ant.2 and reference Ant.2 are two dual-polarized antennas. The only difference between the Ant.1, 2 and reference Ant.1, 2 is the T-shaped slots. The simulated realized gains of Ant.1 and reference Ant.1 are shown in Fig. 3. It can be observed that the realized gains of these two antennas are nearly the same. In other word, etching T-shaped slot on reference Ant.1 has no effect on its

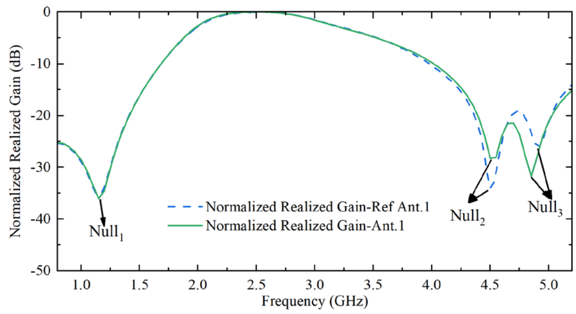


Fig. 3. Simulated normalized gain of the Ant.1 and Reference Ant.1.

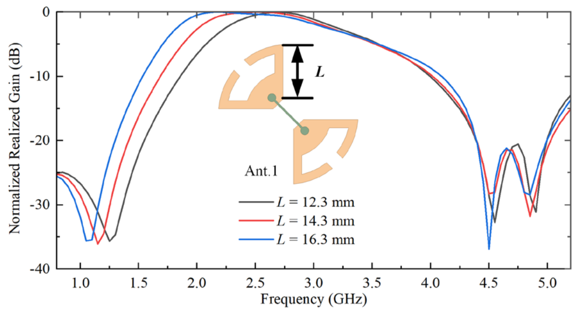


Fig. 4. Ant.1's simulated normalized gain under various L.

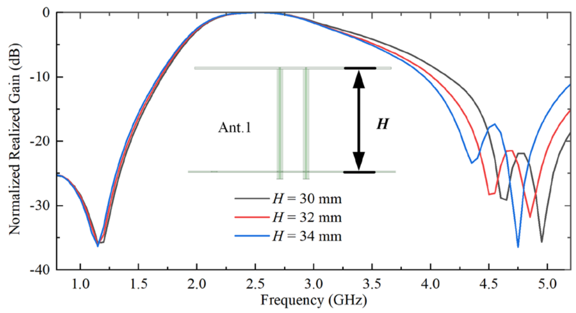


Fig. 5. Ant.1's simulated normalized gain under various H.

performance. Three radiation nulls can be found in lower and higher out-of-band of the Ant.1.

To have a deeper insight into the radiation nulls of these radiation nulls, parameter studies are given in Fig. 4 and 5. As shown in Fig.4, the first radiation null at lower frequency band is related to the length of the dipole arms. The first radiation null shifts towards lower frequency band when the length L increases. When L changes from 12.3 mm to 16.3mm, the first radiation null move from 1.3 GHz to 1.1 GHz. Fig. 5 depicts Ant.1's simulated normalized gains under various H. As depicted, the second and third radiation null are closely related to the height of the Ant.1. when the height of the antenna become smaller, these two radiation nulls shift towards higher frequency band. It is worth noting that the parameters mentioned above can adjust the target radiation null without influencing other radiation nulls. This is very important in the design of filtering antennas.

Fig. 6 shows the simulated realized gain of Ant.2 and reference Ant.2. As depicted, Ant.2 obtains one more radiation null than the reference Ant.2. The new radiation null

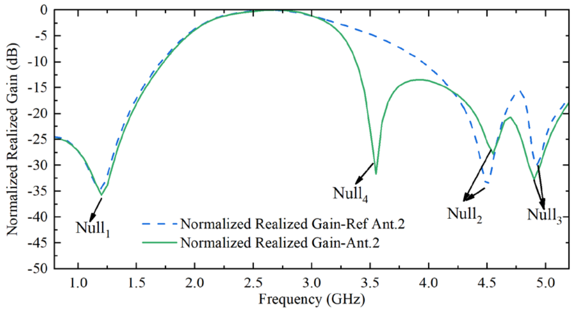


Fig. 6. Simulated normalized realized gain of the Ant.2 and Reference Ant.2.

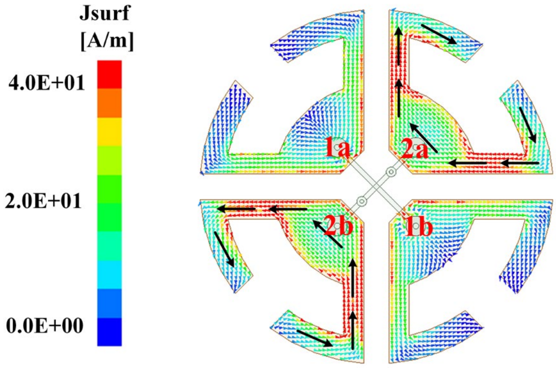


Fig. 7. Simulated current distribution on Ant.2 at 3.5 GHz

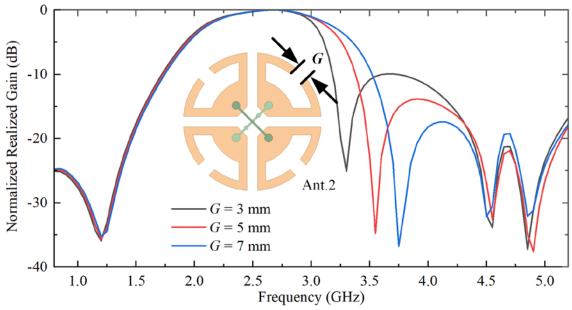


Fig. 8. Ant.2's simulated normalized gain under various G.

appears at 3.5 GHz. The simulated current on radiator of Ant.2 is given in Fig.7 in order to explain the operation principle of fourth radiation null. As depicted, when port 1a and 1b are excited, the current density concentrates on arms of the dipole that is not excited. Each arm can be seen as a split loop resonator. At its resonant frequency, all the power will be coupled to it and then returned to the source. Hence, a radiation null can be achieved at the split loop resonators' resonant frequency. The frequency of the radiation null can be obtained approximately by using:

$$f = {}^{c}/_{2L_{slr}} \tag{5}$$

Where L_{slr} represents the length of the split loop resonator. c is the speed of the light.

Simulated realized gains of Ant.2 under different G is shown in Fig. 8. As can be observed, the fourth radiation null move towards 3.8 GHz from 3.5 GHz when the gap G changes

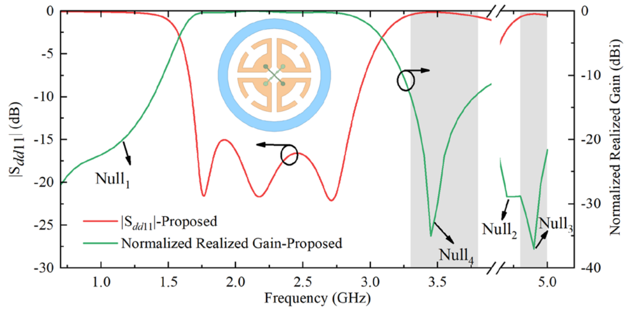
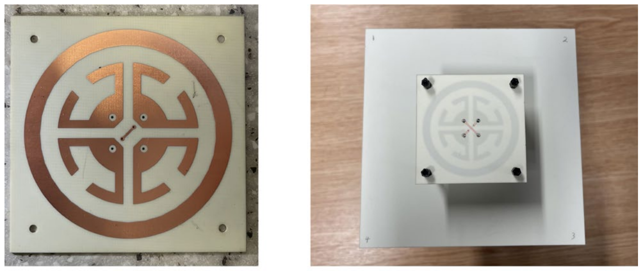


Fig. 9. The normalized gain and $|S_{dd11}|$ obtained from HFSS software.



(a) (b)

Fig. 10. Fabricated prototype of the proposed antenna.

from 3mm to 7mm. Hence, the resonant frequency of the split loop resonator (fourth radiation null) can be adjusted with no effect on other radiation nulls by changing the value of G.

Finally, by combining the modified radiator with a circular parasitic structure, a filtering antenna with dual-polarization, wide impedance bandwidth and good out-of-band rejection level at the two sub-6 GHz bands for the fifth-generation mobile communication system is realized. As given in Fig. 9, the impedance bandwidth of the proposed dual-polarized antenna can cover 1.71 GHz – 2.86 GHz with the reference of $|S_{dd11}| < -14$ dB. The realized gains of the developed antenna are 13 dB and 22 dB lower than the average in-band gain in the two sub-6G bands. The highest rejection level are 35 dB and 36 dB at these two bands. So, when we put this antenna in a multiband base station, it will have little influence on other antennas due to its high gain suppression performance at out-of-band.

III. Results and Discussion

To verify the effectiveness of the presented design principle, a prototype of the presented antenna was made and tested. The picture of the fabricated prototype is shown in Fig. 10. The measured S-parameters and far-field results are obtained by using the Keysight P9377B Vector Network Analyzer and anechoic chamber in the antenna lab of the University of Kent, respectively.

The tested and simulated S-parameters are given in Fig. 11. As can be observed from the tested results, the developed antenna can cover a wide frequency range from 1.69 GHz to 2.87 GHz. Besides, in n78 and n79 bands, the reflection coefficients are higher than -1.5 dB. It means that nearly all the power will be reflected to the source. It is a little different

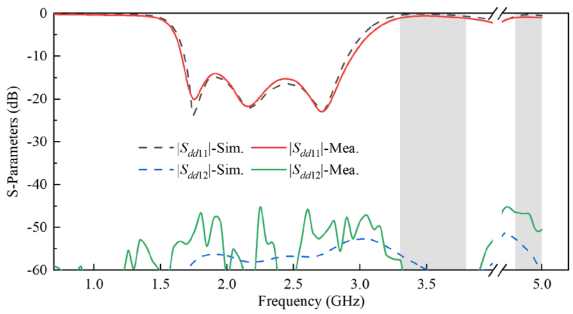


Fig. 11. Measured and simulated |S_{dd11}| and isolation.

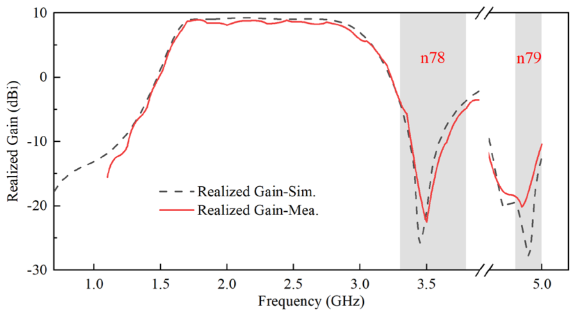


Fig. 12. Measured and simulated realized gain.

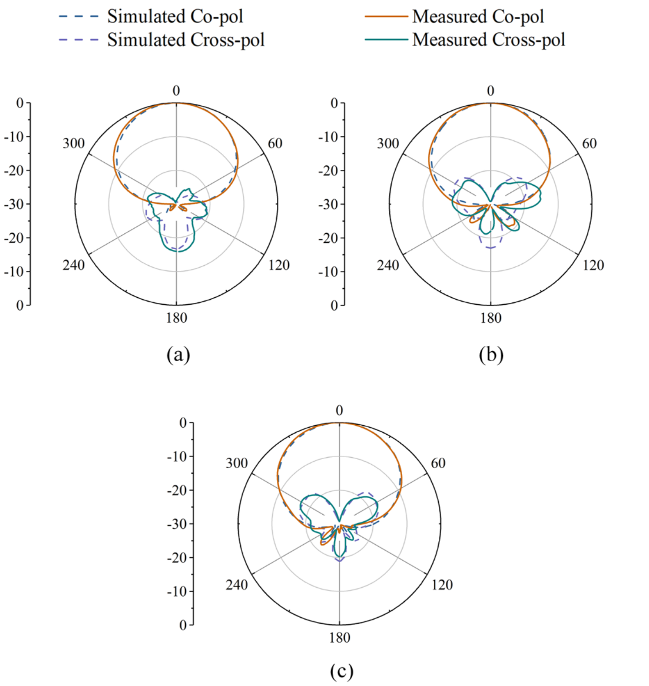


Fig. 13. Measured and simulated normalized radiation patterns of the proposed antenna at (a) 1.7 GHz, (b) 2.2 GHz, and (c) 2.7 GHz.

from the simulated results due to the fabrication error. Because of differentially-fed method, the tested mutual coupling is lower than -40 dB.

Fig. 12 and 13 show the far-field results of the presented antenna. From Fig. 12, we can find that the tested in-band realized gains of the proposed antenna are around 8.5 dB. At 3.3 – 3.8 GHz band, the tested realized gains are lower than -4.6 dBi, and the lowest level reaches -22.5 dBi, which is 31 dB lower than the gain in operating frequency band. At 4.8 – 5.0 GHz, the measured realized gains are lower than -10.4 dBi, and the lowest level reaches -20.2 dBi, which is 28.7 dB lower than the gain in operating frequency band. The simulated and measured radiation patterns of the proposed antenna at the central and edge frequencies are shown in Fig. 13. The tested results are in good agreement with the simulated results. The half power beamwidth of these radiation patterns ranges from 64° to 68°.

TABLE I
COMPARISON OF WIDEBAND FILTERING ANTENNAS WITH DUAL-POLARIZATION

Ref.	Imp. BW	Size (mm)	Rejection at n78 and n79 Band	Gain (dBi)	Iso. (dB)
[2]	1.69-2.77 (48%)	45×45	No; No	~7.7	37
[9]	1.68-3.23 (63%)	50×50	Yes; No	~8.5	32
[15]	*1.81-3.73 (69%)	60×60	No; No	~8.1	30
[16]	1.66-2.73 (49%)	50×50	Yes; No	~8.2	34
This Work	**1.69-2.87 (52%)**	**53×53**	**Yes; Yes**	~8.5	**40**

The reference level of reflection coefficients is -14 dB except [15]. * Means the reference level is -10 dB.

Table I gives a comparison of our antenna and some recently reported designs. The antenna in [2] has a compact size of 45mm×45mm, However, the gain of this antenna is relatively low. The antennas in [9] and [15] have wider impedance bandwidth than our design. However, neither of them has out-of-band rejection in the n79 band. Although the antenna in [16] has the ability to suppress the gain in the n78 band. The impedance bandwidth, gain and isolation of our antenna are better than it.

IV. CONCLUSION

A filtering antenna with dual-polarization, a wide working frequency range, and a good gain suppression level in n78 and n79 bands is proposed in this paper. The effects of some important parameters on the radiation nulls were studied first. Then, by carefully choosing the values of the key parameters and introducing a parasitic loop, a wideband dual-polarized filtering antenna is realized. The measured results demonstrate that the presented antenna can not only cover 1.69-2.87 GHz band, but also suppress the radiation in n78: 3.3-3.8 GHz and n79: 4.8 -5.0 GHz band. Such a high-performance filtering antenna can be a good candidate to reduce the mutual couplings in multi-band base stations.

ACKNOWLEDGMENT

This work was supported in part by EPSRC under Grant EP/S005625/1 and EP/N032497/1, in part by Huawei Technologies Ltd, and in part by China Scholarship Council.

REFERENCES

[1] L. H. Ye, X. Y. Zhang, Y. Gao and Q. Xue, "Wideband dual-polarized four-folded-dipole antenna array with stable radiation pattern for base-station applications, " *IEEE Trans. Antennas Propag.*, vol. 68, no. 6, pp. 4428-4436, June 2020.

[2] L. -H. Wen et al., "Compact dual-polarized shared-dipole antennas for base station applications, " *IEEE Trans. Antennas Propag.*, vol. 66, no. 12, pp. 6826-6834, Dec. 2018.

[3] J. Li, S. -J. Hao, Y. -G. Cui and X. Chen, "A miniaturized wideband dual-polarized planar antenna based on multiresonance, " *IEEE Antennas Wireless Propag. Lett.*, vol. 21, no. 2, pp. 242-246, Feb. 2022.

[4] H. Huang, Y. Liu and S. Gong, "A broadband dual-polarized base station antenna with anti-interference capability, " *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 613-616, 2017.

[5] Y. Liu, S. Wang, N. Li, J. -B. Wang and J. Zhao, "A compact dual-band dual-polarized antenna with filtering structures for sub-6 GHz base station applications, " *IEEE Antennas Wireless Propag. Lett.*, vol. 17, no. 10, pp. 1764-1768, Oct. 2018.

[6] Q. -X. Chu, Y. -L. Chang and J. -P. Li, "Crisscross-shaped ±45° dual-polarized antenna with enhanced bandwidth for base stations, " *IEEE Trans. Antennas Propag.*, vol. 69, no. 4, pp. 2341-2346, April 2021.

[7] K. -R. Xiang, F. -C. Chen, Q. Tan and Q. -X. Chu, "Design of novel printed filtering dipole antennas, " *IEEE Trans. Antennas Propag.*, vol. 69, no. 5, pp. 2537-2545, May 2021.

[8] S. Fu, Z. Cao, X. Quan and C. Xu, "A broadband dual-polarized notched-band antenna for 2/3/4/5G base station, " *IEEE Antennas Wireless Propag. Lett.*, vol. 19, no. 1, pp. 69-73, Jan. 2020.

[9] C. F. Ding, X. Y. Zhang and M. Yu, "Simple dual-polarized filtering antenna with enhanced bandwidth for base station applications, " *IEEE Trans. Antennas Propag.*, vol. 68, no. 6, pp. 4354-4361, June 2020.

[10] H. Yuan, F. -C. Chen and Q. -X. Chu, "A wideband and high gain dual-polarized filtering antenna based on multiple patches, " *IEEE Trans. Antennas Propag.*, doi: 10.1109/TAP.2022.3177494.

[11] X. Liu, S. Gao, B. Sanz-Izquierdo and H. Zhang, "A novel differentially-fed dual-polarized filtering antenna for base station, " *2022 International Workshop on Antenna Technology (iWAT)*, 2022, Dublin, Ireland, pp. 13-16.

[12] W. Yu, H. Lin, B. Liao and W. Duan, "A compact dual-polarized low-pass filtering antenna with wideband out-of-band rejection, " *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 12, pp. 2329-2333, Dec. 2021.

[13] W. Yang, M. Xun, W. Che, W. Feng, Y. Zhang and Q. Xue, "Novel compact high-gain differential-fed dual-polarized filtering patch antenna, " *IEEE Trans. Antennas Propag.*, vol. 67, no. 12, pp. 7261-7271, Dec. 2019.

[14] X. Liu et al., "A compact dual-polarized filtering antenna with steep cut-off for base-station applications, " *IEEE Trans. Antennas Propag.*, vol. 70, no. 7, pp. 5941-5946, July 2022.

[15] Y. Zhang, X. -Y. Zhang and Q. -H. Liu, "Dual-polarized filtering magneto-electric dipole antenna utilizing intrinsic highpass filter network and integrated lowpass filter network, " *IEEE Trans. Antennas Propag.*, vol. 69, no. 12, pp. 8090-8099, Dec 2021.

[16] C. F. Ding, X. Y. Zhang, Y. Zhang, Y. M. Pan and Q. Xue, "Compact broadband dual-polarized filtering dipole antenna with high selectivity for base-station applications, " *IEEE Trans. Antennas Propag.*, vol. 66, no. 11, pp. 5747-5756, Nov. 2018.

[17] X. Liu et al., "A mutual-coupling-suppressed dual-band dual-polarized base station antenna using multiple folded-dipole antenna, " *IEEE Trans. Antennas Propag.*, 2022. doi: 10.1109/TAP.2022.3209177.