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A dual-band filtenna with improved gain using AMC for 5G sub-6 GHz applications

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Research Paper

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Abstract

A gain enhanced dual-band filtenna operating at frequency bands of 3.5 and 5.3 GHz for 5G sub-6 GHz applications is presented in this article. A dual-band antenna is integrated with a filter to improve selectivity. The antenna uses printed monopoles as the radiating element, and the filtering response is achieved using a modified feedline. The designed filtenna is $50 \times 38 \times 1.63\ mm^3$ in size with a maximum gain of 2.5 dBi. The novel filtenna design is equipped with an artificial magnetic conductor (AMC) for the first time to enhance the performance. A unit cell for the AMC is designed that offers zero phase shift in the desired frequencies. A four by four AMC array is designed using this unit cell, which is used as a reflective surface to improve the radiation characteristics of the filtenna. The gain of the filtenna is improved three times up to 7.5 dBi in both bands. The proposed design's overall planar dimensions are $80 \times 80\ mm^2$. Using AMC, the gain has improved with a very minute or no change in the other characteristics. The measured results are congruent with the simulated ones, illustrating that the filtenna has good impedance matching and excellent gain in both bands.

Introduction

With the revolutionary emergence of fifth-generation wireless technology, compact multi-functional components are in great demand. Among the components, filtenna, integration of antenna and filter, performs radiation and filtering operations simultaneously. Here, the antenna is devised to transmit or receive electromagnetic signals, and the filter is responsible for selecting the desired signals in the operating band while rejecting the other signals. The motive behind the design of a filtenna is to reduce the losses and size in a communication system. A few pioneering literature works are band-notched ultra-wideband planar and horn filtering antennas [1], planar monopole filtennas [2–4].

In the traditional filtenna synthesis technique, the last stage of filtering network is replaced by a radiating element [5, 6]. Filters designed using SIW technology and resonators can also be integrated with radiating elements to design filtennas. However, they offer narrow impedance bandwidth, which can be mitigated using a double substrate layer in the former case and defected ground structure (DGS) in the latter [7, 8]. A low-profile two-pole filtenna is designed by uniting a ground-imposed coupled line resonator with a monopole antenna [9]. In another design, a filter consisting of annular resonators is integrated with a fan-shaped patch antenna to realize a flat gain in [10].

For multi-band filtering operation, filters are generally amalgamated into the feed lines of antennas [11–13]. The band notched operation and flexible frequency ratio can be achieved using parasitic elements in multi-band filtennas [14]. Alternatively, radiation nulls can also be shaped by loading shorting pins, different-shaped slots, or stacked patches [15, 16]. A filtenna operating at microwave and millimeter-wave frequencies is designed using a UWB band-stop filter to realize the wide-band separation [17]. Additionally, the gain of printed filtenna can be further improved by using metamaterials such as artificial magnetic conductors (AMC)/high impedance surface (HIS), electronic band-gap [18, 19]. AMC/HIS is designed using a periodic arrangement of a fundamental element called a unit cell in two dimensions. The unit cell is designed such that the periodic surface offers an in-phase or 0° phase reflection and almost unit amplitude in the frequency of interest. This, along with other unique reflection and transmission properties of these surfaces, allures many applications in antennas. There are multifold reports that demonstrate performance improvement in antennas using AMC/HIS such as impedance bandwidth enhancement and gain improvement [20–23].

In this communication, a dual-band filtenna is proposed for 3.3–3.55 and 5.25–5.45 GHz, which are the promising sub-6 GHz frequency bands for 5G wireless communication systems. The dual-band filtering operation is realized using $\lambda_g/4$ resonators inserted into the feed line of the dual-band monopole antenna operating at frequencies 3.5 and 5.35 GHz. Further, the gain of the designed filtenna is enhanced by placing it over an AMC consisting of periodically arranged metallic unit cells. The organization of the paper is as follows.

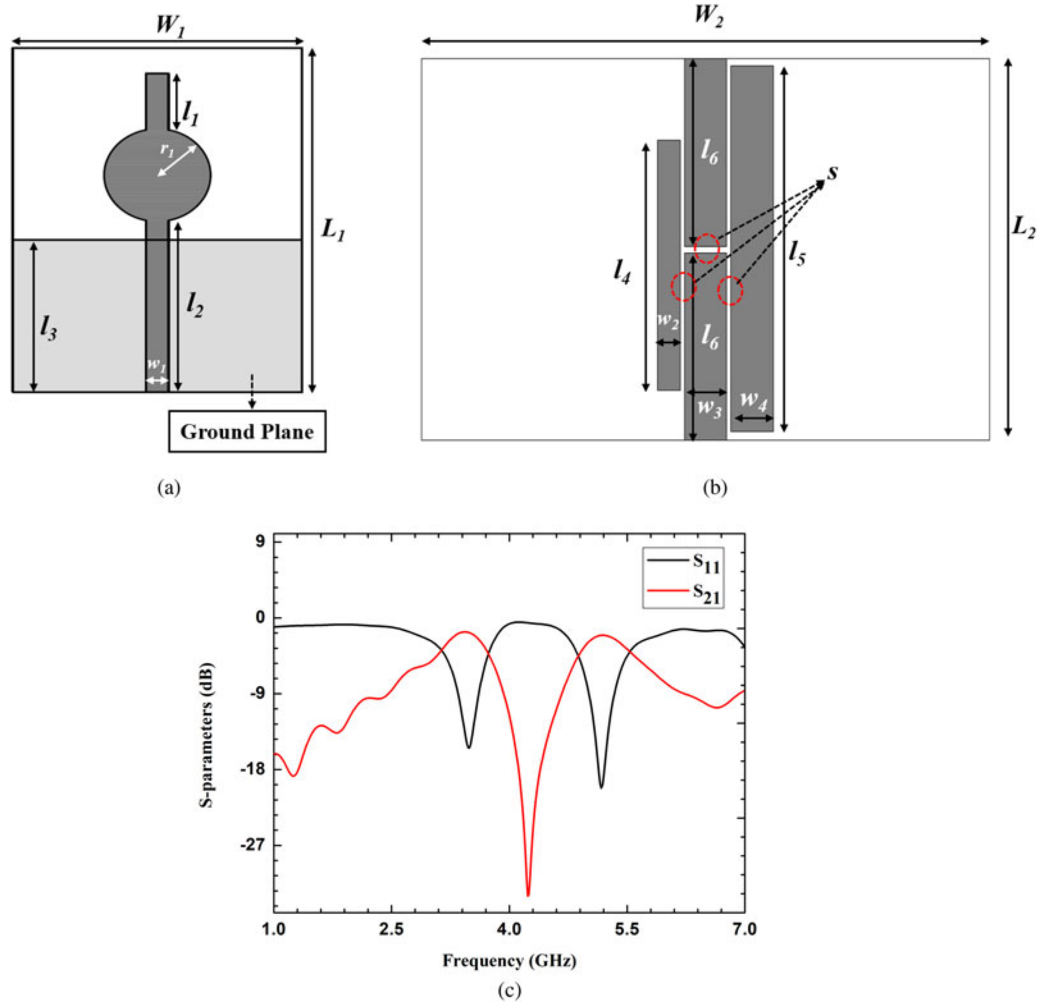

Fig. 1. (a) Dual-band antenna. (b) Dual-band bandpass filter. (c) *S*-parameters of the filter.

Table 1. Optimized dimensions of the proposed dual-band antenna and bandpass filter

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W_1	38	r_1	7	l_6	12.8
L_1	52	L_2	22.9	w_2	1.6
l_1	8.8	W_2	40	w_3	2.93
l_2	25.9	l_4	15	w_4	3
l_3	23	l_5	22	s	0.4
w_1	2.93				

Proposed filtenna design and structure are described in section "Filtenna configuration and design". Section "Gain improvement of filtenna using AMC" details the gain enhancement of the filtenna using AMC structure. Section "Results and discussion" discusses the results and experimental verification of the proposed structures. Lastly, a summary of the work is concluded in section "Results and discussion". The designs in this communication use *FR4* substrate ($\varepsilon_r = 4.3$, thickness = 1.6 mm) and a loss tangent (tan δ) of 0.025. The simulated results are calculated by Computer Simulation Technique-Microwave Studio (CST MWS) software. The equivalent circuit analysis is performed using ADS, and measurements have been done using VNA and anechoic chamber.

Filtenna configuration and design

Dual-band antenna and filter

Firstly, an antenna is designed to operate in the desired bands using microstrip line-fed printed monopole technique. A printed circular

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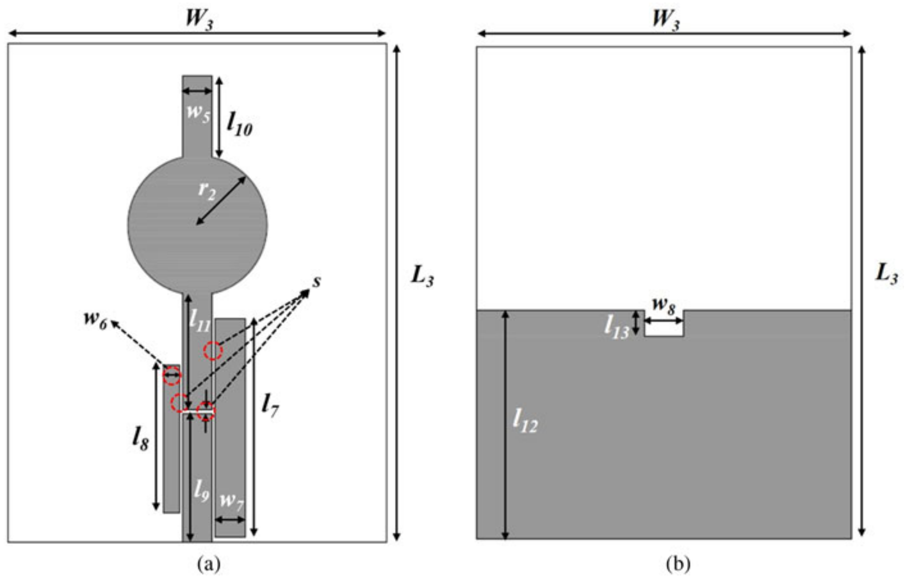

Fig. 2. Proposed dual-band filtenna. (a) Top view. (b) Bottom view.

Table 2. Optimized dimensions of the proposed dual-band filtenna and AMC

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
W_3	38	l_{12}	23.2	s	0.4
L_3	50	l_{13}	2.6	x_1	80
l_7	21.9	w_5	2.93	y_1	80
l_8	14.9	w_6	1.6	d_x, d_y	4
l_9	12.8	w_7	3	s_x, s_x	16
l_{10}	8.2	w_8	4	l_s	2
l_{11}	11.65	r_2	7	h_f	10

monopole operating at 3.5 GHz is loaded with another monopole at 5.3 GHz, as shown in Fig. 1(a). The antenna has a partial ground plane covering up to the feed line of the antenna. A dual-band band pass filter is designed to operate at 3.3–3.55 and 5.25–5.45 GHz. A gap coupled microstrip line with 50 Ohm impedance is chosen, coupled with $\lambda_g/4$ resonators operating at the desired frequency bands on either side, as depicted in Fig. 1(b). The optimized dimensions of the dual-band antenna and filter are given in Table 1. Figure 1(c) depicts the characteristics of the filter. The dual-band filter operates at 3.5 and 5.3 GHz. The dual-band filter has a transmission zero around 4.1 GHz with a more than −30 dB rejection level.

Dual-band filtenna

Next, the dual-band bandpass filter is integrated with the designed dual-band antenna to realize a dual-band filtenna operating at 3.5 and 5.3 GHz. The antenna feedline is modified with the designed filter structure, as shown in Fig. 2. The parameters are optimized to achieve the radiating as well as filtering performance at two desired operating bands. The designed structure of dual-band filtenna is shown in Fig. 2, and the optimized dimensions are detailed in Table 2.

Gain improvement of filtenna using AMC

An AMC is placed at the rear side of the proposed dual-band filtenna as a reflective surface to refine the radiation characteristics. AMC is a surface that mimics the characteristics of a PMC by providing an in-phase reflection at the resonant frequency. The unit cell of the AMC uses *FR4* substrate ($\varepsilon_r = 4.3$, thickness = 1.6 mm). The design of the unit cell is started with a square metallic patch which gave a zero reflection phase around 3.65 GHz. An inverted L-shaped slot is etched into this, as shown in Fig. 3(a). The slot introduced another zero reflection phase at 5.3 GHz and moved the lower resonance near 3.5 GHz. The unit cell is simulated, and the reflection phase is shown in Fig. 3(a). From Fig. 3(a), it is evident that the unit cell has two zero crossings in the reflection phase centered at 3.5 and 5.3 GHz, respectively. The unit cell offers 0° phase shift in the waves reflected from its surface at these frequencies.

Using this unit cell, an AMC is designed which is used as a reflective surface at the back of the filtenna. The AMC is designed with 4×4 array of the designed unit cell. Figure 3(c) shows the detailed structure of the AMC. The dimensions of AMC are $80 \times 80 \times 1.635\ mm^3$. The filtenna and the AMC are separated by a distance h_f. The optimal h_f value is found to be 10 mm using parametric analysis. The side view of the filtenna with

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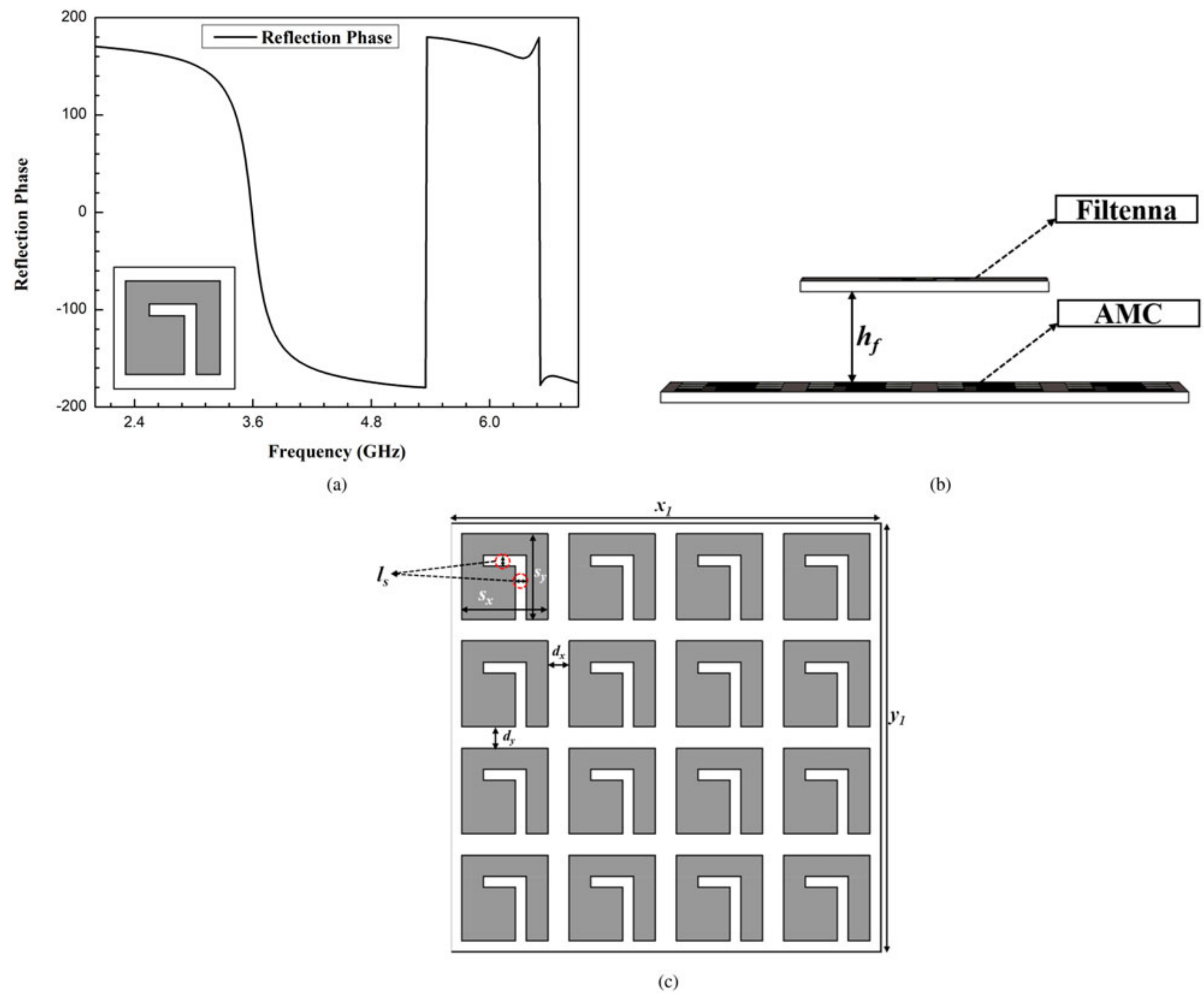

Fig. 3. (a) Unit cell and its reflection phase. (b) Side view of the filtenna and AMC. (c) Proposed AMC surface.

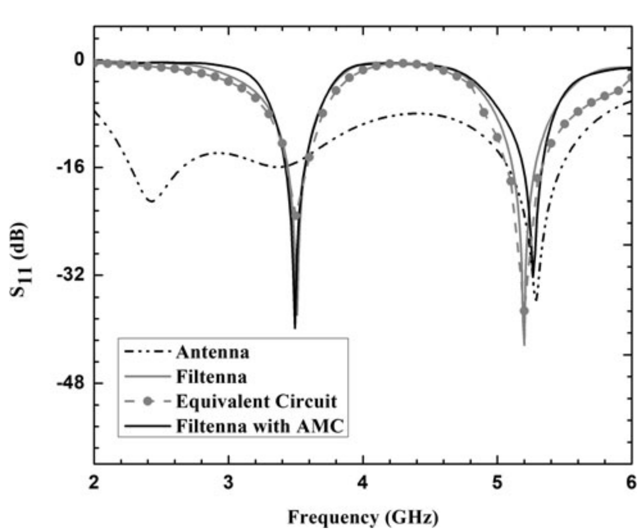

Fig. 4. Simulated S_{11}.

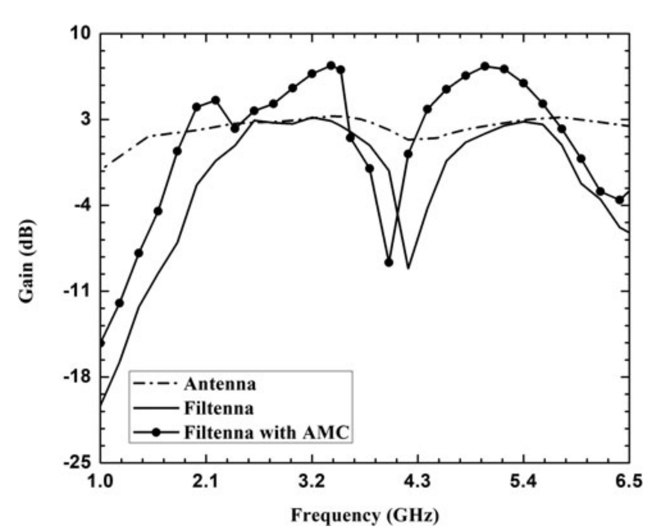

Fig. 5. Simulated gain.

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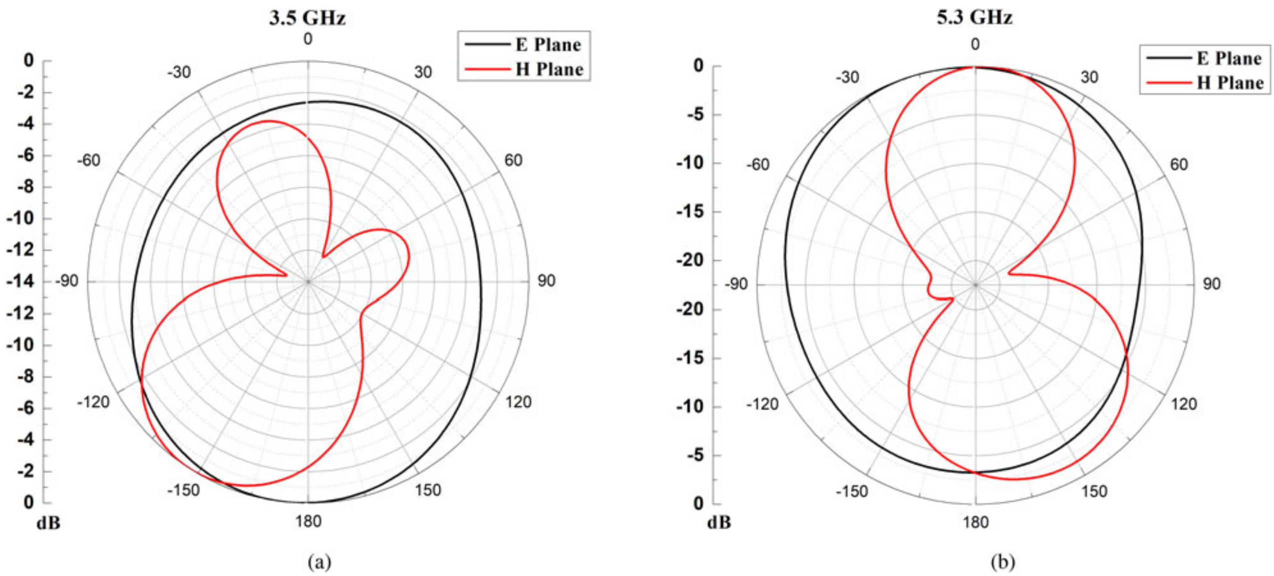

Fig. 6. Radiation pattern of the filtenna. (a) 3.5 GHz, (b) 5.3 GHz.

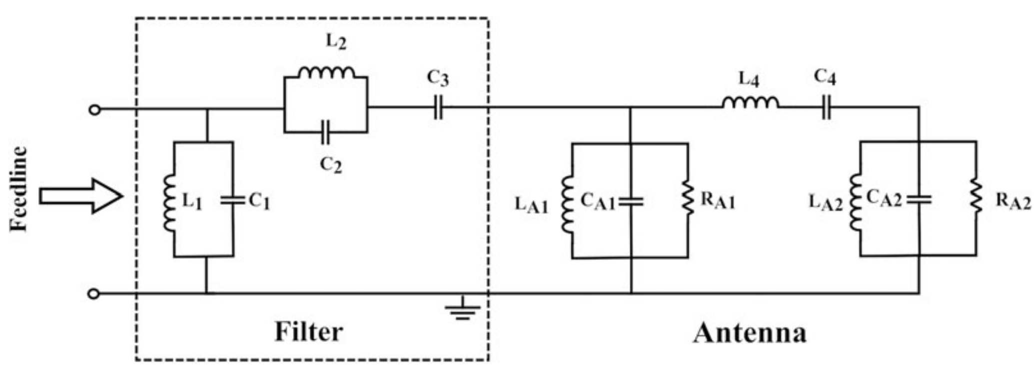

Fig. 7. Equivalent circuit of the proposed filtenna.

Table 3. Optimized dimensions of the proposed dual-band filtenna and AMC

Element	Value	Element	Value	Element	Value
L_1 (nH)	0.98	C_1 (pF)	2.1	C_3 (pF)	0.12
L_2 (nH)	1.55	C_2 (pF)	0.57	C_4 (pF)	0.75
L_4 (nH)	0.2	C_{A1} (pF)	2.1	R_{A1} (Ω)	1.59
L_{A1} (nH)	0.98	C_{A2} (pF)	0.57	R_{A2} (Ω)	10
L_{A2} (nH)	1.55				

AMC is shown in Fig. 3(b), and all the dimensions are detailed in Table 2.

Results and discussion

Figures 4 and 5 depict the comparison of simulated S_{11} and gain of the dual-band antenna and filtenna. The antenna operates in two bands with a broader bandwidth from 2.3 to 3.8 and 4.8 to 5.4 GHz, respectively. The dual-band antenna has nearly a constant gain of 2.5 dBi in the entire band of operation. The filtenna shows a noticeable improvement in selectivity, and it resonates at 3.5 and 5.3 GHz with 10 dB impedance bandwidths of 250 and 200 MHz, respectively. The filter introduced a transmission zero around 4.0 GHz, improving the selectivity of the filtenna. The filtenna has a maximum gain of 2.5 dBi in both the desired bands of operation. It is observed that there is a considerable suppression of the gain in the undesired bands of the filtenna. The *E*- and *H*-plane radiation patterns of the filtenna at both the resonating frequencies are shown in Fig. 6. The pattern at both frequencies is omnidirectional.

An equivalent circuit model is developed for the filtenna, as shown in Fig. 7. The equivalent circuit has two parts, filtering and a radiating part. The filtering part comprises two resonators where L_1, C_1 resonate at 3.5 GHz and L_2, C_2 resonate at 5.3 GHz. C_3 is the coupling capacitor corresponding to the step at $\lambda/4$ resonator in the feedline and the circular monopole. The radiating part is shown as antenna in Fig. 7. Here, the resonator with L_{A1}, C_{A1}, and R_{A1} corresponds to 3.5 GHz, and the resonator with L_{A2}, C_{A2}, and R_{A2} corresponds to 5.3 GHz. L_4 and C_4 correspond to the coupling between both the resonators. The response of the equivalent circuit model is compared to that of the filtenna in Fig. 4. All the element values in the equivalent circuit model are listed in Table 3.

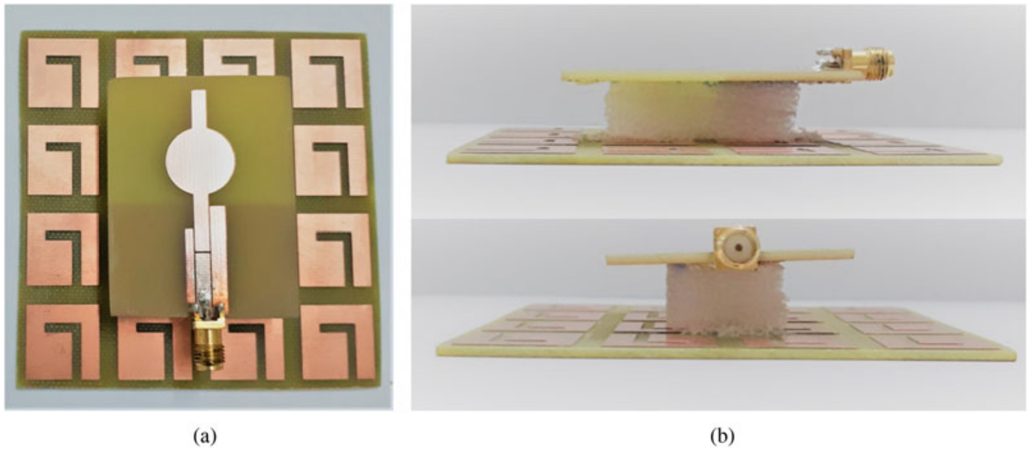

Fig. 8. Fabricated prototype of the filtenna with AMC. (a) Front view. (b) Side view.

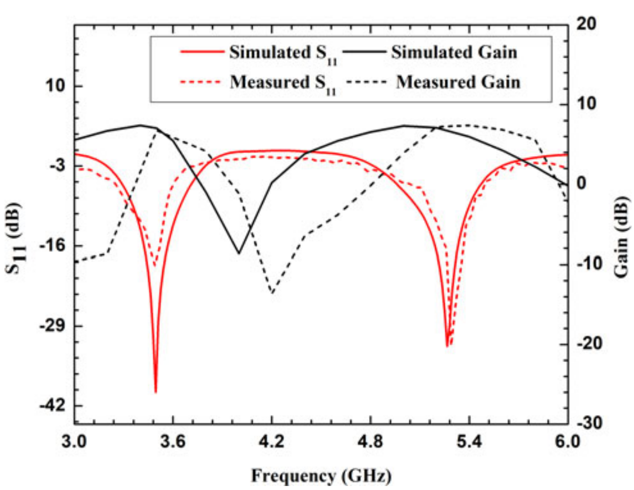

Fig. 9. Measured and simulated S_{11} and gain of the filtenna with AMC.

The designed filtenna is backed with an AMC consisting of a 4×4 array of the unit cell as discussed in section "Gain improvement of filtenna using AMC" to modify the radiation characteristics of the filtenna. Figures 4 and 5 show the comparison of the simulated S_{11} and the simulated gain of the filtenna and filtenna with AMC. The filtenna with AMC operates in the desired bands of frequencies as filtenna, whereas the peak gain of the filtenna with AMC in both the bands is 7.5 dBi. A remarkable gain improvement of 5 dB is observed in both the bands when filtenna is equipped with AMC as a reflective surface.

Finally, the designed filtenna with AMC is fabricated using the lithography technique and characterized. The fabricated prototype of the filtenna with AMC is shown in Fig. 8. The filtenna is placed on the AMC surface using foam with approximately unity relative permittivity. The filtenna, foam, and the AMC structure is secured using cello tape as shown in the side view of the arrangement in Fig. 8(b). Figure 9 shows the comparison of measured S_{11} and gain of the fabricated prototype of dual-band filtenna with AMC with that of the CST MWS simulation. The S_{11} is −19.097 and −32.169 dB at 3.5 and 5.3 GHz, respectively, with

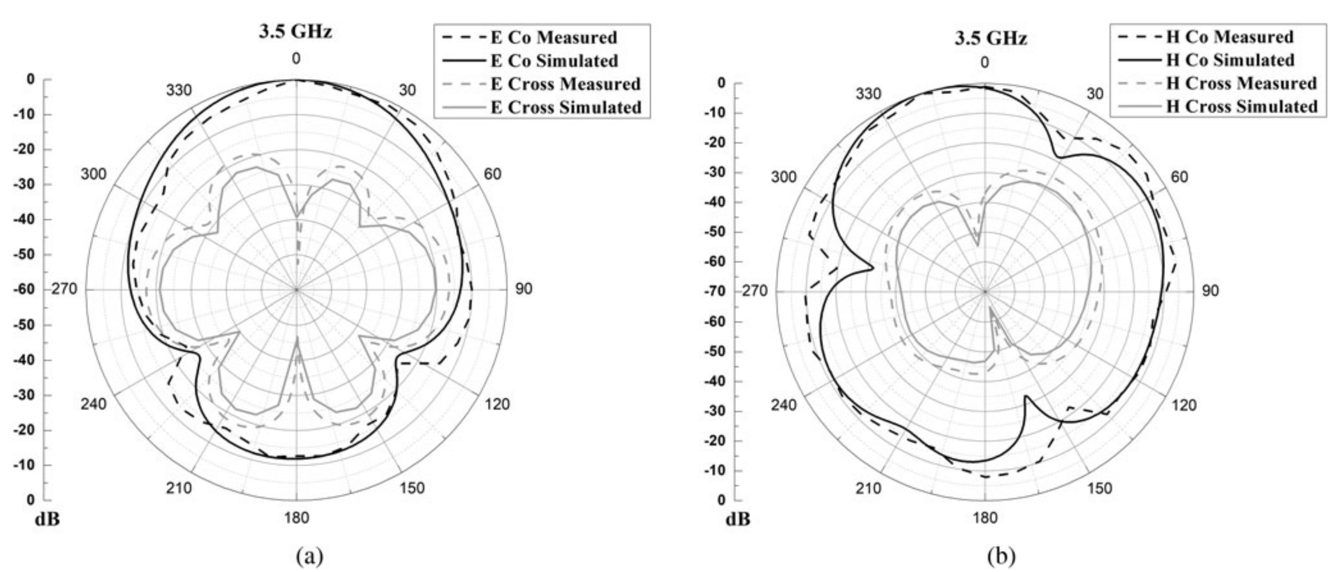

Fig. 10. Radiation pattern of the filtenna with AMC at 3.5 GHz. (a) *E*-plane. (b) *H*-plane.

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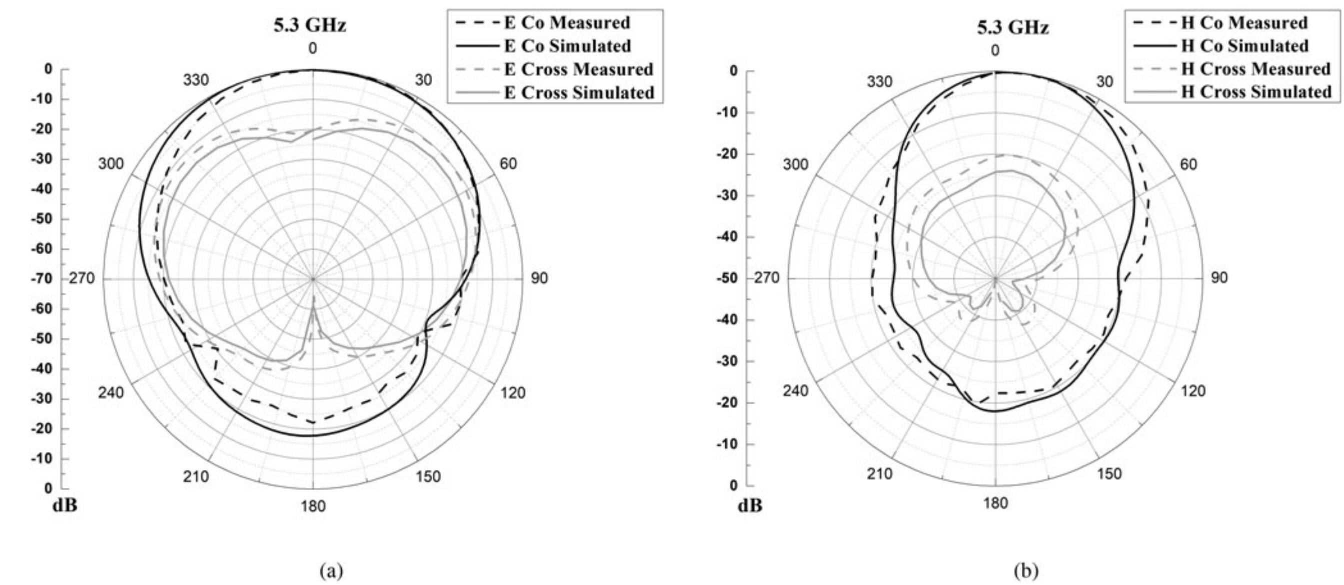

Fig. 11. Radiation pattern of the filtenna with AMC at 5.3 GHz. (a) *E*-plane. (b) *H*-plane.

Table 4. Comparison of the proposed structure with filtennas reported in literature

Ref.	No. of bands	Frequency of operation (GHz)	Filtenna configuration	Gain (dBi)	Bandwidth (MHz)	Size (mm^3)
[1]	2	3.95, 6	Microstrip, reconfigurable	1.5, 6.1	Tunable	34 × 27 × 0.787
[2]	1	2.4	Microstrip, synthesis approach	0.74	180	35 × 30 × 1.635
[3]	1	2.45	Microstrip	2.16	605	30 × 40.8 × 0.6
[4]	1	2.4	Microstrip	2.41	400	30 × 50 × 0.6
[5]	1	2.35	Microstrip	1.4	196	29 × 27 × 1
[6]	1	2.45	Microstrip	1.21	300	83.3 × 83.3 × 0.8
[8]	2	11.575, 17.875	Microstrip, DGS	5.76, 6.14	700, 1800	34 × 16 × 1.6
[10]	1	2.4	Microstrip, DGS	2.3	460	47 × 35 × 1.52
[11]	2	5.2, 10	Microstrip (stacked structure) 2 × 2 array	10, 12 (gain of array)	240, 460	–
[12]	2	3.6, 5.2	Microstrip (stacked structure)	6.5, 7	50, 150	–
[14]	2	1.98, 2.59	Microstrip (parasitic elements)	3.38, 4.5	380, 510	–
[17]	2	5.2, 28	Microstrip (filter in ground)	4.09, 6.18	791, 4760	4.3 × 28.5 × 0.254
This work	2	3.5, 5.3	Microstrip, reflective AMC	7.5, 7.5	250, 200	80 × 80 × 13

a gain of 7.505 and 7.504 dBi, respectively. It is seen that the proposed filtenna works well for 3.3–3.55 and 5.25–5.45 GHz with almost constant gain within these bands. The maximum achieved gain is 7.5 dBi in both bands. Figures 10 and 11 show the radiation pattern of filtenna with AMC in *E*- and *H*-planes at 3.5 and 5.3 GHz, respectively. The measured and simulated patterns are in good agreement. On comparing with Fig. 6, the directionality of the pattern is improved to a great extent, corresponding to the increased gain with AMC. The cross-polarization levels in the major lobe direction for *E*- and *H*-planes are observed to be −40 and −45 dB at 3.5 GHz and −28 and −30 dB at 5.3 GHz, respectively. The cross-polarization levels are well within the acceptable level for both the resonating frequencies.

Table 4 compares the proposed filtenna with some filtennas reported in the literature. Single and dual-band filtenna designs using microstrip technology are considered for comparison. It can be observed that the proposed filtenna has less circuit complexity, easy integration of filter with the antenna, and has high gain in both the operating bands. Ref. [11] has a higher gain which uses a 2 × 2 array of the filtenna element. For filtennas operating in the sub-6 GHz range, the proposed design offers high gain with relatively less complicated technology, ease of fabrication, and the design uses FR4 substrate making the overall design inexpensive.

Conclusion

The dual-band filtenna incorporated with an AMC has been proposed for gain enhancement. The proposed filtenna has a planar structure and exhibits nearly constant gain from 3.3 to 3.55 and 5.25 to 5.45 GHz, with an improvement of 5 dB. From the simulation as well as measurement, it is found that the AMC can be placed inverted without disturbing the filtenna performance and gives similar results with orientation in L-slot or inverted L-slot of AMC unit cell. Also, the proposed design can be used with or without AMC depending upon the gain requirements. All the measured results are congruent with the simulated ones. However, minute variations are due to fabrication errors or due to the SMA connector.

Conflict of interest. None.

References

1. **Tang M-C, Wang H, Deng T and Ziolkowski RW** (2016) Compact planar ultrawideband antennas with continuously tunable, independent band-notched filters. *IEEE Transactions on Antennas and Propagation* **64**, 3292–3301.
2. **Pal P, Sinha R and Mahto SK** (2021) Synthesis approach to design a compact printed monopole filtenna for 2.4 GHz Wi-Fi application. *International Journal of RF and Microwave Computer-Aided Engineering* **31**, e22619, 1–8.
3. **Wu W, Wang C, Wang X and Liu Q** (2013) Design of a compact filter-antenna using DGS structure for modern wireless communication systems. In *2013 5th IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*. IEEE, Chengdu, China.
4. **Wu W-J, Yin Y-Z, Zuo S-L, Zhang Z-Y and Xie J-J** (2011) A new compact filter-antenna for modern wireless communication systems. *IEEE Antennas and Wireless Propagation Letters* **10**, 1131–1134.
5. **Tang M-C, Chen Y and Ziolkowski RW** (2016) Experimentally validated, planar, wideband, electrically small, monopole filtennas based on capacitively loaded loop resonators. *IEEE Transactions on Antennas and Propagation* **64**, 3353–3360.
6. **Wu W-J, Yin Y-Z, Xie J-J, Ren X-S and Zuo S-L** (2012) Low-cost microstrip filter antenna with a monopole-like radiation pattern for RF front end. *Microwave and Optical Technology Letters* **54**, 1810–1814.
7. **Mishra SR and Kochuthundil Lalitha S** (2019) Filtennas for wireless application: a review. *International Journal of RF and Microwave Computer-Aided Engineering* **29**, e21879.
8. **Mishra SR and Lalitha SK** (2020) Implementation of defected ground structure for microstrip filtenna design. *International Journal of RF and Microwave Computer-Aided Engineering* **30**, e21998, 1–12.
9. **Chuang C-T and Chung S-J** (2011) A compact printed filtering antenna using a ground-intruded coupled line resonator. *IEEE Transactions on Antennas and Propagation* **59**, 3630–3637.
10. **Chen X, Zhao F, Yan L and Zhang W** (2013) A compact filtering antenna with flat gain response within the passband. *IEEE Antennas and Wireless Propagation Letters* **12**, 857–860.
11. **Mao C-X, Gao S, Wang Y, Luo Q and Chu Q-X** (2017) A shared-aperture dual-band dual-polarized filtering-antenna-array with improved frequency response. *IEEE Transactions on Antennas and Propagation* **65**, 1836–1844.
12. **Mao CX, Gao S, Wang Y, Sanz-Izquierdo, B, Wang, Z, Qin, F, Chu, QX, Li, J, Wei, G, and Xu, J** (2016) Dual-band patch antenna with filtering performance and harmonic suppression. *IEEE Transactions on Antennas and Propagation* **64**, 4074–4077.
13. **Hsieh C-Y, Wu C-H and Ma T-G** (2015) A compact dual-band filtering patch antenna using step impedance resonators. *IEEE Antennas and Wireless Propagation Letters* **14**, 1056–1059.
14. **Niu B-J, Tan J-H and Wong S-W** (2019) A printed dual-band dipole filtenna with flexible frequency ratio and improved band-notched performance. *International Journal of RF and Microwave Computer-Aided Engineering* **29**, e21675.
15. **Zhang Y, Zhang XY, Ye L-H and Pan Y-M** (2016) Dual-band base station array using filtering antenna elements for mutual coupling suppression. *IEEE Transactions on Antennas and Propagation* **64**, 3423–3430.
16. **Zhang XY, Duan W and Pan Y-M** (2015) High-gain filtering patch antenna without extra circuit. *IEEE Transactions on Antennas and Propagation* **63**, 5883–5888.
17. **Dardeer OM, Elsadek HA, Elhennawy HM and Abdallah EA** (2021) Single-fed dual wideband filtenna for 4G/5G mobile applications. *International Journal of RF and Microwave Computer-Aided Engineering* **31**, e22616, 1–12.
18. **Al-Hasan MJ, Denidni TA and Sebak AR** (2013) Millimeter-wave EBG-based aperture-coupled dielectric resonator antenna. *IEEE Transactions on Antennas and Propagation* **61**, 4354–4357.
19. **Yang W, Wang H, Che W and Wang J** (2013) A wideband and high-gain edge-fed patch antenna and array using artificial magnetic conductor structures. *IEEE Antennas and Wireless Propagation Letters* **12**, 769–772.
20. **Akhoondzadeh-Asl L, Kern DJ, Hall PS and Werner DH** (2007) Wideband dipoles on electromagnetic bandgap ground planes. *IEEE Transactions on Antennas and Propagation* **55**, 2426–2434.
21. **Raad HR, Abbosh AI, Al-Rizzo HM and Rucker DG** (2013) Flexible and compact AMC based antenna for telemedicine applications. *IEEE Transactions on Antennas and Propagation* **61**, 524–531.
22. **Prakash P, Abegaonkar MP, Basu A and Koul SK** (2013) Gain enhancement of a CPW-fed monopole antenna using polarization-insensitive AMC structure. *IEEE Antennas and Wireless Propagation Letters* **12**, 1315–1318.
23. **Elzwawi GH, Mantash M and Denidni TA** (2017) Improving the gain and directivity of CPW antenna by using a novel AMC surface. In *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*. IEEE, San Diego, CA, USA.

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surfaces at microwave and mm-wave frequencies for 4G/5G applications, and RF energy harvesting.

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