A Compact Dual-band Planar Antenna Loaded with Magneto Dielectric Ferrite

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Abstract – In this paper, a compact dual-band planar antenna loaded with magnetodielectric ferrite is proposed for ISM/GSM/UMTS. Slot and ring structures are dual-resonant mode generators of the antenna. And the characteristic mode analysis is used for the modeling, analysis, and optimization of the proposed antenna. Because of the loading of a piece of rectangular Co_2W hexaferrite medium, this antenna can be used in lower frequency bands. The electromagnetic parameters of this ferrite are measured by the transmission line method. Finally, the antenna is fabricated and measured. The operation frequency band ($S_{11}<-10$ dB) is determined to be 80 MHz (890–970 MHz) and 370 MHz (1.87–2.24 GHz) with the dual resonance frequencies of 925 MHz and 2.175 GHz, respectively, which is capable for ISM (915 MHz)/GSM900/UMTS applications.

Index Terms – dual-band, miniaturized antenna, magnetodielectric ferrite, characteristic mode analysis, planar antenna.

I. INTRODUCTION

With the arrival of 5G, wireless communication equipment integrates more and more applications. A communication device needs to work in multiple frequency bands. Many multiple-input–multiple-output (MIMO) antennas have been proposed to solve this problem [1–4]. MIMO antenna conforms to the development trend of communication. At the same time, the compatibility design of MIMO antenna elements is relatively complex. And broadband antenna is also an inevitable trend [5–7]. The design of a miniaturized planar broadband antenna is very difficult and demanding. Therefore, to make full and accurate use of spectrum resources, the design of a multi-frequency antenna is more in line with the actual needs. In recent years, many types of research on multi-frequency antennas have been proposed. In comparison with patch antennas, slot antennas have advantages including easier implementation of multiband, wider potential bandwidth, and more stability to fabrication tolerances [8]. Among them, the slot structure composed of multiple rings is widely used. A compact multiband circularly polarized (CP) slot antenna loaded with metallic strips and a split-ring resonator (SRR) is proposed in [9]. The use of SRR or new structures derived from SRR can enlarge bandwidth, produce resonance frequency, and change radiation polarization, etc. In [10], a ring monopole antenna coupled with an electric-inductive-capacitive (ELC) meta material element achieves better return loss characteristics. In [11], the use of a hexagonal complementary split-ring resonator (HCSRR) is capable of creating a new resonance frequency for an antenna. The paper [12] shows that the combination of multiple structures can produce multi-frequency characteristics. The change of the ground plane can also affect the resonance characteristics of the antenna. In article [13], the design of using SRRs on the partial ground plane generates multiple circularly polarized bands. In [14], the metasurface (MS)-based artificial ground composed of CRRS is loaded on the dual-band antenna. SRR and MS structures have great advantages for the design of multi-frequency antennas.

With the rapid development of circuit integration, the size of wireless communication equipment is getting smaller and smaller, leaving less and less space for the antenna. The existing miniaturized antenna has been difficult to meet the space given by the increasingly highly integrated equipment. The dielectric material loading method is a useful and promising technique to make a better performance for antennas [15]. Magnetic and dielectric properties are the two main physical properties used by many electronic components. In the past, the research on the miniaturization of microwave devices relatively focuses on the innovation of device structure and advanced manufacturing and packaging technology. More attention should be paid to new media materials with high performance. Ferrite with both dielectric and magnetic properties deserves attention. At present, the research of antenna miniaturization by improving the structure has reached the bottleneck, and the research of antenna miniaturization by using high-performance media is becoming more and more important. Recently, some novel

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high-frequency magnetodielectric properties ferrites for RF and microwave device applications have been synthesized [16, 17].

The research of high-frequency magnetodielectric properties ferrites loaded antenna will be of great significance. In this paper, a compact dual-band antenna with magnetodielectric ferrite loaded is proposed for ISM (915 MHz)/GSM900/UMTS. Because of the loading of a piece of magnetodielectric ferrite, the presented antenna can be used in lower frequency bands. The arrangement of ferrite affects the radiation characteristics of an antenna. The proposed antenna is fabricated and measured. For the operation band, the proposed antenna provides very relatively small size and good performance. The antenna is designed and analyzed in Section II. The results of the antenna are analyzed in Section III, followed by conclusion in Section IV.

II. DESIGN AND ANALYSIS OF DUAL-BAND ANTENNA

The configuration of the proposed compact dual-band antenna with magnetodielectric ferrite loaded is illustrated in Figure 1. The antenna is fabricated in an FR4 substrate with the thickness of 1.6 mm, dielectric constant of 4.4 and dielectric loss of 0.02. The top layer of the antenna as shown in Figure 1 (a) consists of two square rings (TSRs) and a patch connected by stubs. The feed mode of the antenna is side feed, and the feed line is also on the upper surface of the antenna. The bottom layer of the antenna as shown in Figure 1 (b) consists of a square ring ground plane (SRGND) and an H-shaped structure with an angle of 45° to the feed line. Figure 1 (c) is the side view of this antenna. A rectangular Co_2W hexaferrite medium with thickness of 0.6 mm, relative dielectric constant of 14, and relative permeability frequency dependent was loaded at the gap of TSRs on the upper surface. The Key sight materials measurement suite is used to measure the electromagnetic parameters of this ferrite. The result of the measurement is shown in Figure 2.

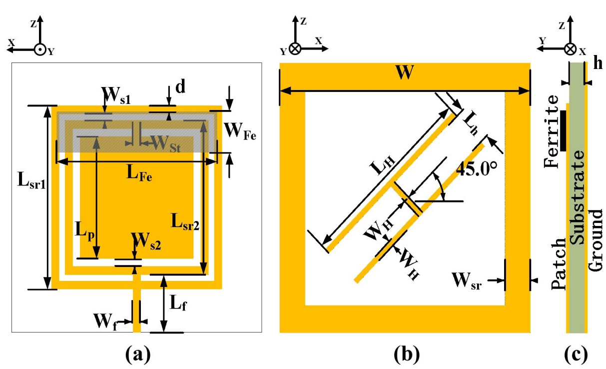

Fig. 1. Configuration of the proposed antenna. (a) top view, (b) bottom view, (c) side view. (Unit: mm W = 50, H = 1.6, L_{Fe} = 33, W_{Fe} = 7, L_{sr1} = 34, L_{sr2} = 28.6, d = 1.5, W_{st} = 1.5, L_f = 10.7, W_f = 1.5, W_{srt} = 5, L_H = 18, L_p = 22.6, W_{s1} = 1.2, W_{s2} = 1.7, W_H = 1, L_h = 7.).

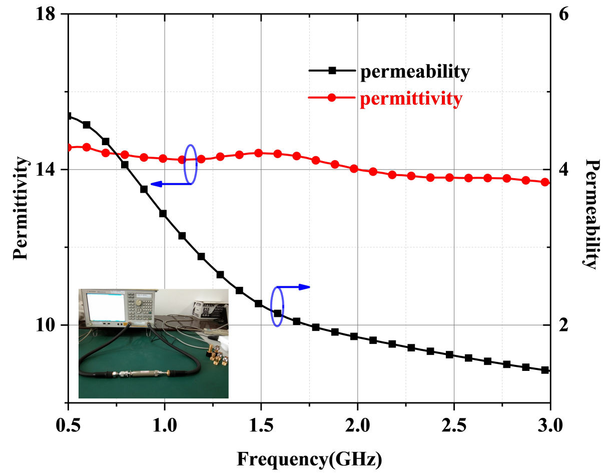

Fig. 2. The measurement results of the permittivity and permeability of the ferrite used in this paper.

A. Analysis of the dual-band antenna without ferrite

The resonant mode generated by the discrete elements of the antenna is the basis for generating dual bands [8, 18]. This can be analyzed by applying the theory of characteristic mode (TCM) to the elements under consideration. A more convenient way to measure the resonant frequency and potential contribution to the radiation of a mode is to define the Modal Significance (MS) whose range is 0 to 1. The mode resonates and radiates the most efficiently when MS = 1 [19, 20].

TSR and SRGND structures are designed to apply the ferrites mentioned above. As shown in Figure 3, the resonant mode of the TSR is at 2.4 GHz, which is a half-wavelength resonance, and that of the SRGND are at 1.6 GHz and 2.7 GHz, which are a half-wavelength resonance and a full-wavelength resonance. It can be observed that the resonant modes of the two main elements of the antenna are distributed at about 1.6 GHz and 2.5 GHz. In order to make the resonant modes of the two elements work together, a patch is designed in the center of the TSR, forming a TSR + Patch structure (TSRP). Two square slots formed by TSRP can generate two resonant modes [8]. It can be seen from Figure 3 that the resonant modes of TSRP designed in this paper are 2.13 GHz and 1.68 GHz. According to the reference [21, 22], an asymmetric structure can affect the mechanism of dual-band resonance; this paper designs a tilted H-shaped structure at the bottom to form an asymmetric ground plane and adjust the dual-band res-

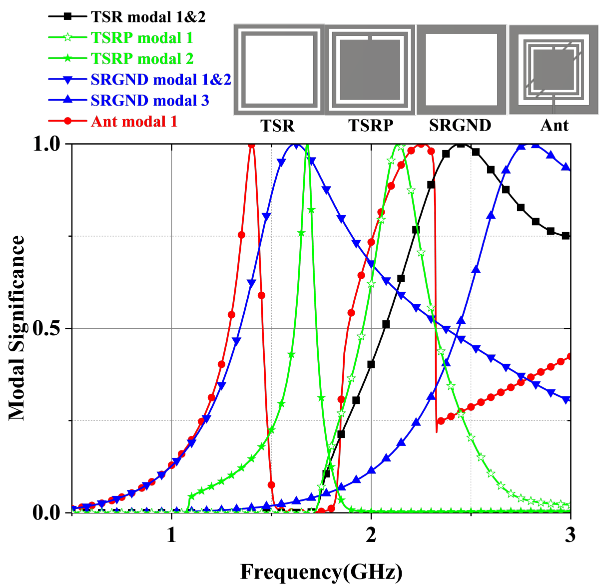

Fig. 3. The modal significance of TSR, SRGND, and the antenna without ferrite. (The frequency range from 0.5 GHz to 3 GHz.).

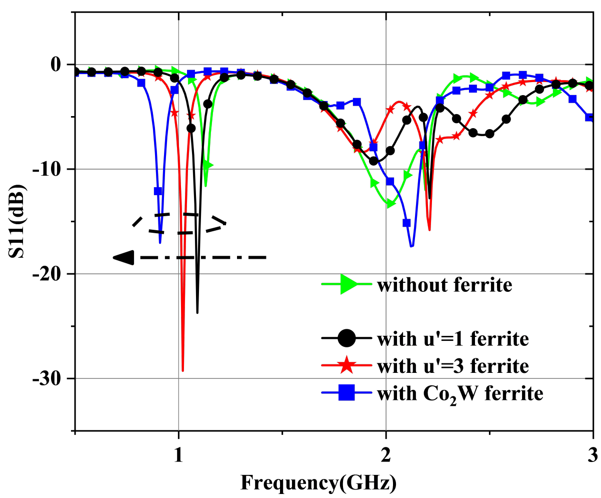

Fig. 4. The simulation S_{11} of the proposed antenna without ferrite and the simulation S11 of the antenna with different permeability ferrite (Other parameters of ferrite keep the same as the Co2W hexaferrite).

onance point of the antenna. Finally, Ant is obtained. It can be seen from Figure 3 that there are two resonant modes of the Ant, one at 1.4 GHz and the other at 2.2 GHz. It can be seen that the resonant frequency of the whole antenna migrates toward the lower frequency. Through the above method we design a dual-band antenna, and the simulation S_{11} parameters are shown in Figure 4.

B. Compact dual-band planar antenna with ferrite loading

The wavelength of the electromagnetic wave in a medium is largely affected by a factor $(n = n(\mu^{'}\varepsilon^{'})1/2$, where $\mu^{'}$ is the real part of permeability and $\varepsilon^{'}$ is the real part of permittivity). The size of the antenna is also closely related to the n of the loaded medium [17]. In this paper, a Co_2W hexaferrite is used. As can be seen from Figure 2, the value of permittivity is relatively stable with frequency, while the permeability decreases sharply with the increase of frequency. Therefore, the ferrite load should have a greater impact on the antenna's low-frequency operating band. The simulation S_{11} of the antenna loaded with a ferrite having the same permittivity and different permeability is shown in Figure 4. In the simulation, only the permeability of ferrite is changed. As the permeability increases, the resonance frequency of the antenna in the low frequency operation band shifts to the left. When Co_2W hexaferrite is loaded on the proposed antenna, the low frequency operation band of the antenna will move to a lower frequency band. The miniaturization of the antenna is realized in this way. To study the effect of ferrite loading on the radiation characteristics of the antenna, the current distribution comparison of the antenna before and after ferrite loading is shown in Figure 5. Through the comparison of Figure 5 (a) and (b), it can be concluded that the current of the antenna with the proposed structure is concentrated near the ferrite when the ferrite is loaded. It can be seen from Figure 5 (c) and (d) that the effect

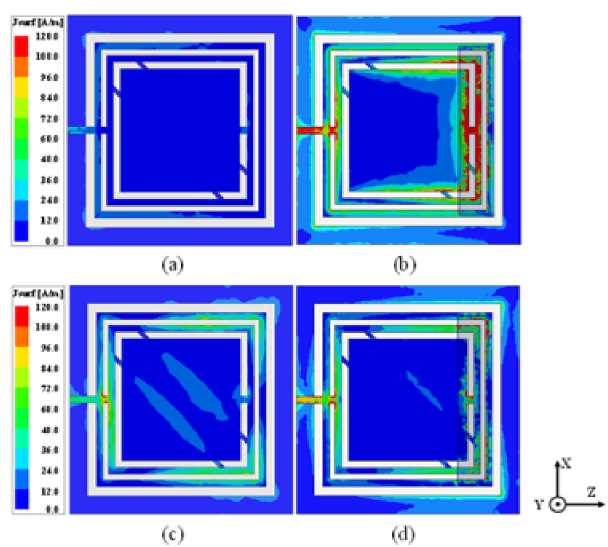

Fig. 5. The current distribution comparison of the presented antenna. (a) at 0.925 GHz, without ferrite, (b) at 0.925 GHz, with ferrite, (c) at 2.175 GHz, without ferrite, (d) at 2.175 GHz, with ferrite.

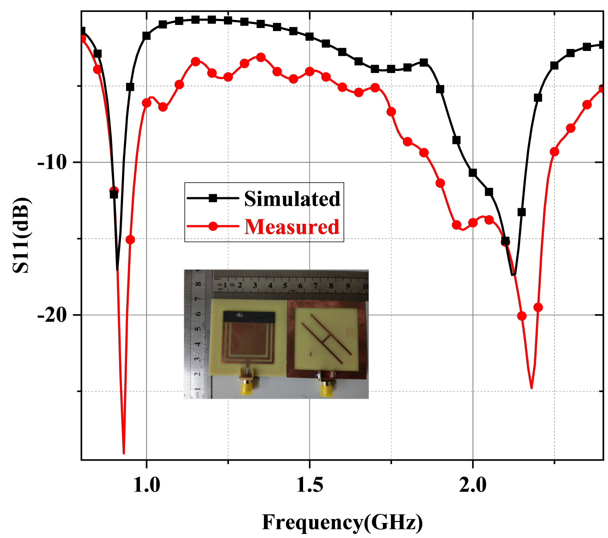

Fig. 6. The simulation and measurement S_{11} of the proposed compact dual band antenna with magnetodielectric ferrite loading.

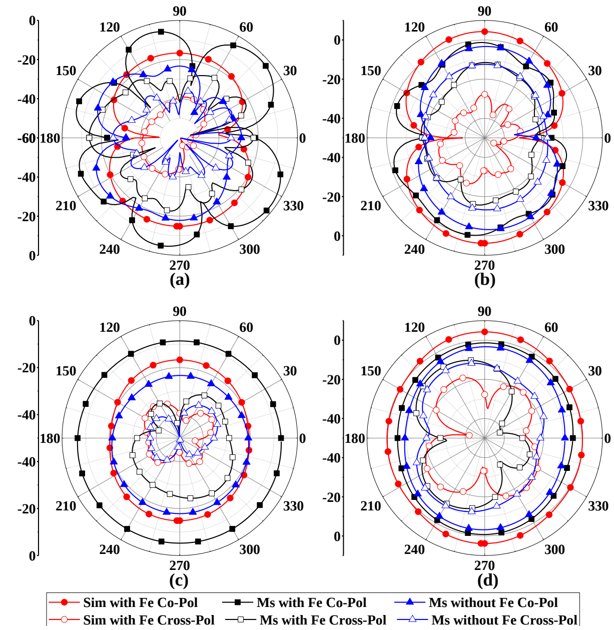

Fig. 7. 2-D radiation patterns of antenna simulation and measurement. (a) E-plane (yoz-plane) at 0.925 GHz, (b) E-plane (yoz-plane) at 2.175 GHz, (c) H-plane (xoy-plane) at 0.925 GHz, (d) H-plane (xoy-plane) at 2.175 GHz.

of ferrite loading on the antenna is not obvious around 2.175 GHz. The S_{11} of the simulation and measurement of the proposed compact dual-band antenna with magnetodielectric ferrite loading is shown in Figure 6. The error between simulation result and measurement result is caused by processing technology and the test environment.

III. RESULTS

The radiating performance of the proposed antenna is measured in Satimo anechoic chamber. As observed, the yoz-plane is the E-plane while the xoy-plane is the H-plane of the antenna. The 2-D radiation patterns (yoz- and xoy-planes) of the antenna simulation and measurement are plotted in Figure 7. It can be seen from Figure 7 that in the low-frequency operation band, the radiation characteristics of the antenna loaded with ferrite are better than that of the antenna without ferrite, while in the high-frequency operation band, the influence of loaded ferrite on the radiation characteristics of the antenna is not significant. It can be seen from Figure 7 (a) that in low-frequency band, the simulation trend of the antenna loaded with ferrite is consistent with the measured radiation patterns of the E-plane, but the measured co-polarization radiation pattern of the antenna shows sawtooth, which is caused by the irregular surface of ferrite material. This is a problem caused by the processing process, which can be avoided by improving the technology. Figure 8 shows the measurement results of the peak gain of the proposed antenna in this letter. Through comparison, it is found that the radiation performance of the antenna with ferrite is more

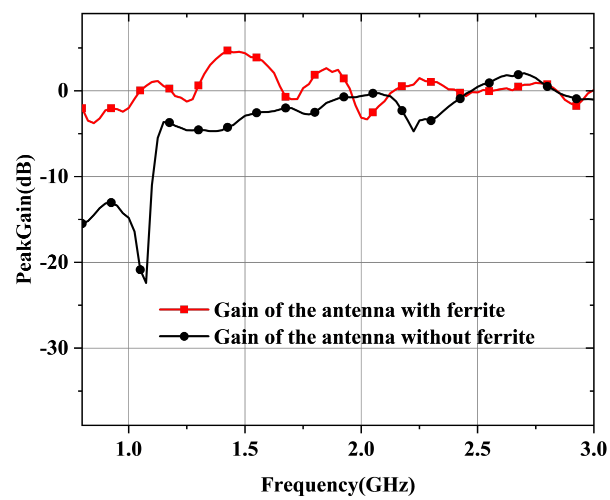

Fig. 8. The measurement peak gain of the proposed antenna.

stable. Furthermore, in Table 1, a comparison of the proposed antenna with the existing multiband antennas is given and it is found that the designed antenna shows improved miniaturized size and fair impedance bandwidth.

Table 1: Performance comparison of the proposed antenna with other reported multi-band antennas

Ref.	Size	Num. of bands (GHz)	Impedance BW(%)	app	Efficiency(%)
[9]	$0.093\lambda^2$	three–1.83, 2.5, 3.1	21.4, 12.8, 4.5	——	75, 90, 82
[10]	$0.14\lambda^2$	two–3.74, 5.1	13.1, 16.7	WiMAX/WLAN	80, 75
[11]	$0.066\lambda^2$	two–2.56, 4.64	7.2, 51.7	ISM/WiMAX/WLAN	——
[12]	$0.054\lambda^2$	two–1.66, 5.69	31.3, 64.85	Bluetooth/WLAN/WiMAX	——
[14]	$0.109\lambda^2$	two–1.88, 2.5	7.5, 12.6	——	——
This work	$0.024\lambda^2$	two–0.925, 2.175	8.6, 18	ISM/GSM/UMTS	22, 54

λ—wavelength in free space corresponding to the lowest resonant frequency.

IV. CONCLUSION

In this letter, a compact dual-band planar antenna loaded with magnetodielectric ferrite has been fabricated and measured. The characteristic mode analysis (CMA) is used for the modeling, analysis, and optimization of the proposed antenna without ferrite in order to reveal the underlying modal behaviors of each radiating element and to guide the mode excitation. The ferrite used in this paper is a ferrite with high frequency, high permeability, high dielectric, and low loss made by our research group. By studying the simulation and measurement data of the antenna loaded with ferrite and not loaded with ferrite, it is verified that the loaded ferrite has a good influence on the radiation performance of the antenna designed in this paper. At the same time, it is proved that the antenna structure combined with Co_2W hexaferrite can realize the antenna miniaturization.

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REFERENCES

[1] M. Sonkki, E. Antonino-Daviu, M. Cabedo-Fabres, M. Ferrando-Bataller, and E. T. Salonen, "Improved planar wideband antenna element and its usage in a mobile MIMO system," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 826-829, Jul. 2012.

[2] J. Tao and Q. Y. Feng, "Compact ultrawideband MIMO antenna with half-slot structure," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 792-795, Apr. 2017.

[3] C. Yang, J. Kim, H. Kim, J. Wee, B. Kim, and C. Jung, "Quad-band antenna with high isolation MIMO and broadband SCS for broadcasting and telecommunication services," *IEEE Antennas Wirel. Propag. Lett.*, vol. 9, pp. 584-587, Jul. 2010.

[4] J. Tao and Q. Y. Feng, "Compact isolation-enhanced UWB MIMO antenna with band-notch character," *J. Electromagn. Waves Appl.*, vol. 30, no. 16, pp. 2206-2214, Jul. 2016.

[5] J. Guo, Y. Zou, and C. Liu, "Compact broadband crescent moon-shape patch-pair antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 435-437, May. 2011.

[6] T. Wu, H. Su, L. Gan, H. Chen, J. Huang, and H. Zhang, "A compact and broadband microstrip stacked patch antenna with circular polarization for 2.45-GHz mobile RFID reader," *IEEE Antennas Wirel. Propag. Lett.*, vol. 12, pp. 623-626, May. 2013.

[7] V. P. Sarin, M. S. Nishamol, D. Tony, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "A broadband l-strip fed printed microstrip antenna," *IEEE Trans. Antennas Propag.*, vol. 59, no. 1, pp. 281-284, Jan. 2011.

[8] J. Li, J. Shi, L. Li, T. A. Khan, J. Chen, Y. Li, A. Zhang, "Dual-band annular slot antenna loaded by reactive components for dual-sense circular polarization with flexible frequency ratio," *IEEE Access*, vol. 6, pp. 64063–64070, Oct. 2018.

[9] P. M. Paul, K. Kandasamy, and M. S. Sharawi, "A triband circularly polarized strip and SRR-loaded slot antenna," *IEEE Trans. Antennas Propag.*, vol. 66, no. 10, pp. 5569-5573, Oct. 2018.

[10] R. S. Daniel, R. Pandeeswari, and S. Raghavan, "Dual-band monopole antenna loaded with ELC metamaterial resonator for WiMAX and WLAN applications," *Appl. Phys. A-Mater. Sci. Process.*, vol. 124, no. 8, p. 570, Jul. 2018.

[11] B. Murugeshwari, R. S. Daniel, and S. Raghavan, "A compact dual band antenna based on metamaterial-inspired split ring structure and hexagonal complementary split-ring resonator for ISM/WiMAX/WLAN applications," *Appl. Phys. A-Mater. Sci. Process.*, vol. 125, no. 9, p. 628, Aug. 2019.

[12] B. Bag, P. Biswas, S. Biswas, and P. P. Sarkar, "Wide-bandwidth multifrequency circularly polarized monopole antenna for wireless communication applications," *Int. J. RF Microw. Comput. Eng.*, vol. 29, no. 3, p. e21631, Nov. 2018.

[13] M. Alam, Mainuddin, B. K. Kanaujia, M. T. Beg, S. Kumar, and K. Rambabu, "A hexa-band dual-sense circularly polarized antenna for WLAN/Wi-MAX/SDARS and C-band applications," *Int. J. RF Microw. Comput. Eng.*, vol. 29, no. 4, p. e21599, Apr. 2019.

[14] T. Yue, Z. H. Jiang, and D. H. Werner, "A compact metasurface-enabled dual-band dual-circularly polarized antenna loaded with complementary split ring resonators," *IEEE Trans. Antennas Propag.*, vol. 67, no. 2, pp. 794-803, Feb. 2019.

[15] A. S. Turk and A. K. Keskin, "Partially dielectric-loaded ridged horn antenna design for ultrawideband gain and radiation performance enhancement," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 921-924, Aug. 2012.

[16] Z. L. Zheng, Y. W. Li, T. Liu, and Q. Y. Feng, "Novel high-frequency magneto-dielectric properties of CaO-SiO2 Co-Doped NiZnCo spinel ferrites for RF and microwave device applications," *IEEE Trans. Magn.*, vol. 54, no. 11, pp. 1-4, Nov. 2018.

[17] Z. L. Zheng, Q. Y. Feng, Q. Y. Xiang, Z. X. Di, and V. G. Harris, "Low-loss NiZnCo ferrite processed at low sintering temperature with matching permeability and permittivity for miniaturization of VHF-UHF antennas," *J. Appl. Phys.*, vol. 121, no. 6, p. 063901, Feb. 2017.

[18] R. Aldhaheri, I. Alruhaili, K. Babu, and M. Sheikh, "A compact CPW-Fed UWB antenna with dual-band notched characteristics for WiMAX/WLAN applications," *Appl. Comput. Electromagn. Soc. J. (ACES)*, vol. 36, no. 2, pp. 145–151, Feb. 2021.

[19] F. H. Lin and Z. N. Chen, "Low-profile wideband metasurface antennas using characteristic mode analysis," *IEEE Trans. Antennas Propagat.*, vol. 65, no. 4, pp. 1706–1713, Apr. 2017.

[20] J. Monica and P. Jothilakshmi, "Multifold bandwidth improvement in conformal patch antenna for aircraft application using corrugated edge coupling," *Appl. Comput. Electromagn. Soc. J. (ACES)*, vol. 36, no. 5, pp. 577–588, May. 2021.

[21] Y. Li, W. Li, and R. Mittra, "A compact ACS-FED dual-band meandered monopole antenna for Wlan and WiMax applications," *Microw. Opt. Technol. Lett.*, vol. 55, no. 10, pp. 2370–2373, Oct. 2013.

[22] Y. Li, W. Li, and Q. Ye, "A compact asymmetric coplanar strip-fed dual-band antenna for 2.4/5.8 GHz Wlan applications," *Microw. Opt. Technol. Lett.*, vol. 55, no. 9, pp. 2066–2070, Sept. 2013.

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