IEICE Communications Express, Vol.13, No.6, 190–194

ComEX

Special Cluster in Antennas and Propagation Technologies 2023

LETTER

Square rod antenna covered by mantle cloak with rejection band at lower frequency side of operating frequency

Shuhei Ozawa[1], **Takumi Nishime**[1], **Hiroshi Hashiguchi**[1], **Naobumi Michishita**[1, a)], **Kiyoshi Sakimoto**[2], **Teruki Miyazaki**[2], **and Masato Tadokoro**[2]

Abstract Mutual coupling reduction is required to miniaturize wireless devices in many applications. The mantle cloak technique has been studied to reduce mutual coupling. This paper proposes a square rod mantle cloak antenna with a low-frequency rejection band. The rejection band is 720 MHz and the operation band is 750 MHz. The proposed antenna structure contains a copper rod-covered dielectric substrate with strip conductors at the center of each face. The proposed antenna was validated by comparing the simulation and measurement results.

Keywords: mantle cloak antenna, mutual coupling reduction, square structure, cloaking

Classification: Antennas and propagation

1. Introduction

Antennas are densely mounted inside smartphones and Internet of Things (IoT) devices for miniaturization, system diversification, high functionality, and designability. In base station antennas for mobile communication, many antennas operating at different frequency bands are installed in limited spaces. Moreover, many car-roof-mounted antennas are placed in small spaces to support multiple bands. In such wireless applications, adjacent frequency bands are used efficiently. Therefore, interference with adjacent systems must be suppressed. To suppress the interference, adjacent systems that use a close operating frequency band require a high-isolation filter. A filter is required to suppress the mutual coupling of the frequency used by adjacent systems while maintaining the antenna characteristics at the operating frequency. Several methods have been proposed to suppress the mutual coupling of antennas. Examples include orthogonal polarization [1], loading a lumped constant circuit between antennas [2], loading a parasitic element between antennas [3], and mushroom-shaped EBG structure [4]. However, most of these methods are difficult to use inside electronic devices because of their narrow space. Additionally, these techniques enable the suppression of the mutual coupling between antennas operating at the same frequency. However, it is difficult to suppress the mutual coupling between antennas that operate at different frequencies. Mantle cloak has been gaining attention for reducing mutual coupling operating at different frequencies. A mantle cloak covers an object to suppress scattering, and incident waves pass through backward objects [5, 6]. A mantle cloak was created by adjusting the surface reactance. Mantle cloak antennas with adjusted surface reactances of dielectric-loaded dipole antennas have been proposed [7, 8, 9, 10, 11]. Reference [7] reported that mutual coupling can be suppressed by covering a cylindrical mantle cloak for dipole antennas operating at 3.33 GHz and 3.07 GHz, respectively. However, the operating frequency interval was 300 MHz. In [8] and [9], mutual coupling suppression was achieved in the 700 MHz band with a 30 MHz interval between the operating frequency and the rejection frequency. These mantle cloak antennas can suppress mutual coupling by applying a cylindrical coating of a high-dielectric material with a surface reactance or strip conductors to the dipole antenna. However, it is difficult to bend high-dielectric materials. In [10], a square rod mantle cloak antenna with an adjusted surface reactance was proposed to facilitate the fabrication. The cloaking effect of the proposed antenna was confirmed through simulation. However, an actual structure with the desired surface reactance is difficult to fabricate owing to its limited size and fabrication accuracy. In [11], a mantle cloak antenna with strip conductors mounted at the four corners of a square rod was proposed. However, it has not been demonstrated yet. In this study, a square rod mantle cloak antenna with strip structures is proposed for its simple structure and ease of fabrication.

2. Proposed structure

In [11], the structure of a square rod mantle cloak antenna with a rejection frequency of 720 MHz and an operating frequency of 750 MHz is presented. The simulation model is illustrated in Fig. 1. Figure 1(a) shows a 750 MHz dipole antenna composed of a copper rod with 10 mm sides. Figure 1(b) shows a square rod dipole antenna with sides of 10 mm and a length of l [mm]. This antenna is covered with a high dielectric material of 1.65 mm thickness with strip conductors of width w [mm] at the center of each face. A 5 mm matching section on each side was placed at the center of the antenna with a gap g [mm]. The power feed is a gap feed with a spacing of 2 mm. The finite element method was used for the simulation, and the parameters were optimized to design the frequency band.

[1] Graduate School of Science and Engineering, National Defense Academy, Yokosuka-shi, Kanagawa, 239-8686, Japan
[2] The Yokohama Rubber Co., Ltd., Hiratsuka-shi, Kanagawa 254-8601, Japan
a) naobumi@nda.ac.jp

DOI: 10.23919/comex.2024SPL0017
Received January 26, 2024
Accepted February 21, 2024
Publicized April 8, 2024
Copyedited June 1, 2024

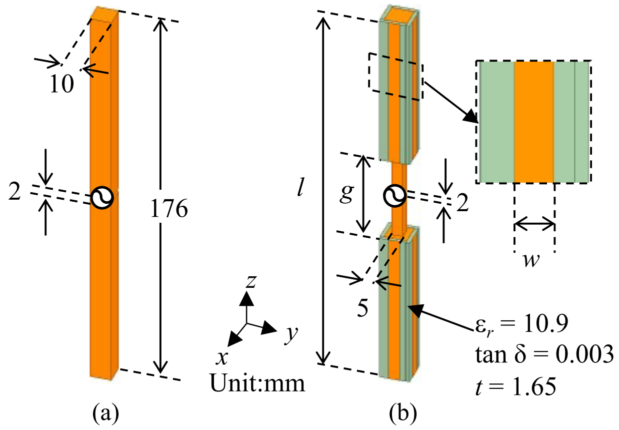


Fig. 1 Simulation model. (a) Dipole antenna, and (b) mantle cloak antenna.

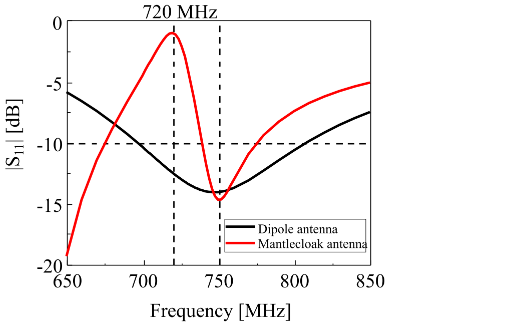


Fig. 2 Comparison between dipole antenna and mantle cloak antenna of simulated reflection characteristics.

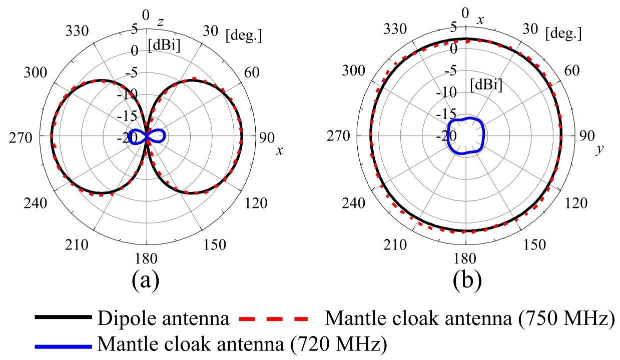


Fig. 3 Comparison between dipole antenna and mantle cloak antenna of simulated radiation patterns. (a) zx-plane, (b) xy-plane.

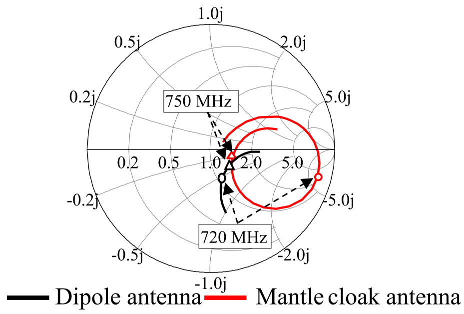


Fig. 4 Comparison between dipole antenna and mantle cloak antenna of simulated input impedance characteristics.

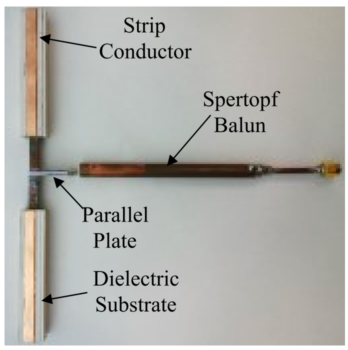


Fig. 5 Prototype antenna structure.

3. Simulation and Measurement result

Figure 2 presents the simulation results of the reflection characteristics with a total length l = 177 mm, strip width w = 4.8 mm, and spacing g = 39 mm. The reflection coefficient of the rejection band at 720 MHz is −0.9 dB. At 750 MHz, the reflection coefficient was less than −10 dB. The radiation patterns of the designed antenna at the operating frequency and the rejection band are shown in Fig. 3. The radiation pattern in the zx-plane is a figure of eight, whereas that in the xy-plane was omnidirectional. This radiation pattern is consistent with that of dipole antennas. The results show that the mantle cloak antenna maintains the characteristics of a dipole antenna at the operating frequencies. The actual gain in the rejection band is greatly reduced owing to mismatch loss. The impedance characteristics of the designed antenna are shown in Fig. 4. The designed antenna has a parallel resonance added to the impedance characteristics of the dipole antenna. Therefore, the rejection band was obtained by a parallel resonance with the strip conductor. Figure 5 displays a photograph of the fabricated antenna. The antenna was fed by a parallel plate and coaxial cable with a Spertopf balun to suppress leakage currents. Figure 6 shows a comparison of the measurements and simulations of the reflection characteristics. An operating frequency of 750 MHz and rejection band at 720 MHz were obtained, as shown in Fig. 6. The measurement results agreed well with the simulation results. Figure 7 presents the measurement results of the radiation pattern at 750 MHz. Radiation patterns of figure of eight and omnidirectional were obtained in the zx-plane, xy-plane, respectively. The measurement results are in good agreement with the simulation results.

The simulation model used to confirm the mutual coupling suppression is shown in Fig. 8. The distance between the antennas is d [mm]. In addition, under the same simulation conditions, the mantle cloak antenna was changed in to a dipole antenna operating at 750 MHz. Figure 9 illustrates the radiation patterns. Figure 9(a) shows the radiation pattern of zx-plane, and Fig. 9(b) shows the radiation pattern of the xy-planes at 720 MHz. The radiation patterns are disturbed by the mutual coupling between the dipole antennas. However, the dipole antenna maintains its antenna characteristics by closely placing the designed mantle cloak antenna. Figure 10 shows the electric field distribution in the zx-plane. The electric field distribution is disturbed by the mutual coupling between the dipole antennas. However, the electric field distribution in undisturbed, owing to the

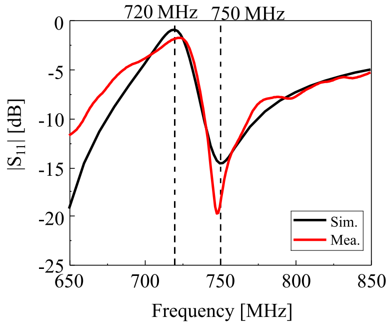


Fig. 6 Comparison between simulated and measured results of reflection characteristics.

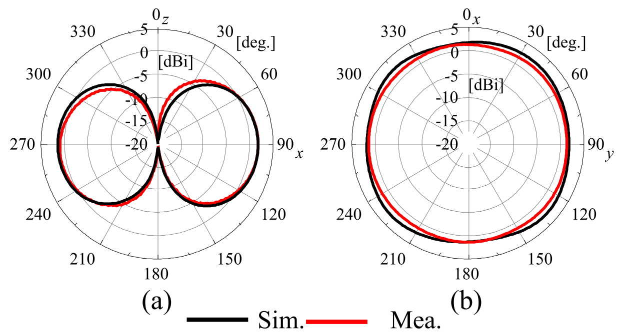


Fig. 7 Comparison between simulated and measured results of radiation patterns at 750 MHz. (a) zx-plane, (b) xy-plane.

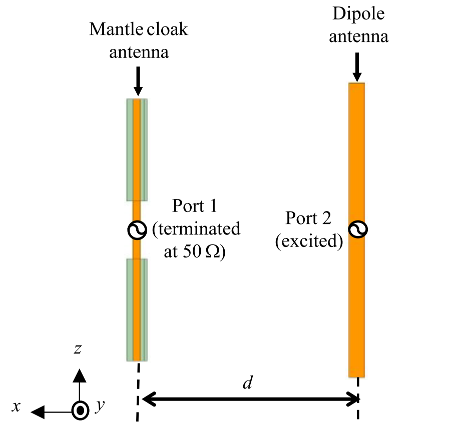


Fig. 8 Simulation model of mutual coupling suppression.

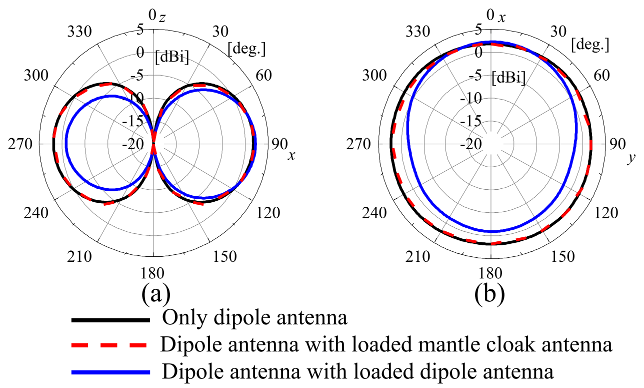


Fig. 9 Comparison of mutual coupling suppression between dipole antenna and mantle cloak antenna in simulated radiation patterns. (a) zx-plane, (b) xy-plane.

cloaking effect of the mantle cloak antenna. Therefore, the square rod mantle cloak antenna suppresses mutual coupling by the cloaking effect. The measurement conditions for the transmission characteristics are illustrated in Fig. 11. A jig was placed on top of the mantle cloak antenna to maintain the distance between the antennas. A dipole antenna was installed in the jig. After measurement, the mantle cloak

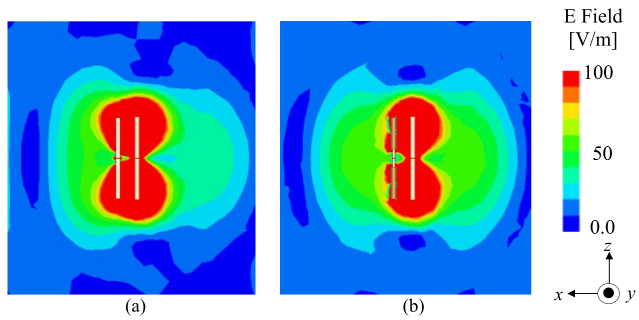


Fig. 10 Comparison of mutual coupling suppression in electric field distributions at 720 MHz. (a) Dipole antenna, (b) mantle cloak antenna.

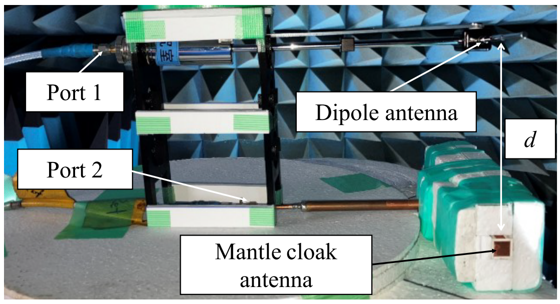


Fig. 11 Measurement setup of transmission characteristics.

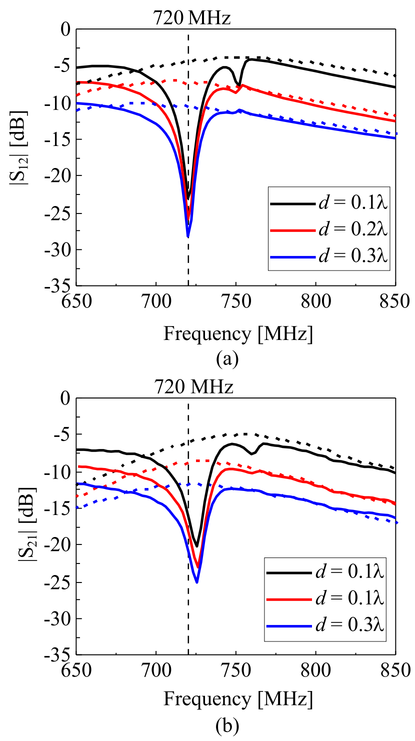
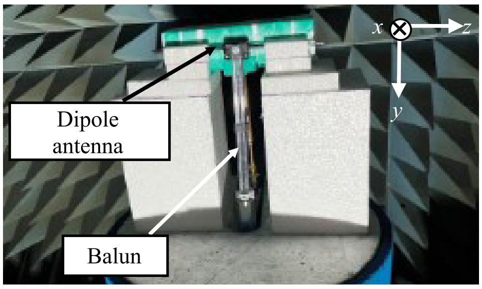


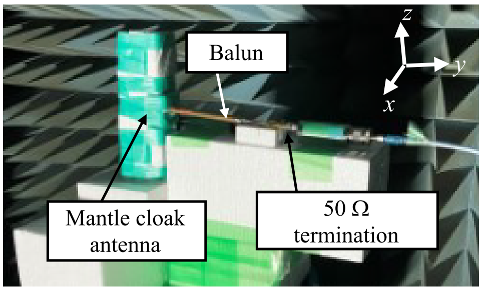
Fig. 12 Comparison of mutual coupling suppression in (a) simulated and (b) measured transmission characteristics by closely placing mantle cloak antenna (solid line) and dipole antenna (dashed line).

antenna was changed to a dipole antenna operating at 750 MHz. Figure 12 shows the transmission characteristics with varying distances d [mm]. The transmission coefficient decreased by approximately 20 dB at 720 MHz. The mutual coupling can be suppressed at 720 MHz even at the distance of 0.1λ between the antennas.

The measurement conditions for the radiation patterns are illustrated in Fig. 13. A dipole antenna operating at 720 MHz and a mantle cloak antenna terminated in 50 Ω is placed close together on a rotating table. After radiation pattern measurement, the mantle cloak antenna is changed to a dipole antenna under the same conditions. The measurement results for the radiation patterns at 720 MHz when $d = 0.1\lambda$ are shown in Fig. 14. Figure 14(a) shows the radiation pattern of the zx-plane, and Fig 14(b) shows that of the xy-plane. The radiation pattern is disturbed because of the mutual coupling caused by the close placement of the dipole antenna. However, the radiation pattern was maintained owing to the cloaking effect of the mantle cloak antenna. These results are in good agreement with the simulation results. Therefore, the validity of the simulation results was confirmed.



(a)



(b)

Fig. 13 Measurement set up of radiation patterns at 720 MHz when $d = 0.1\lambda$. (a) zx-plane, (b) xy-plane.

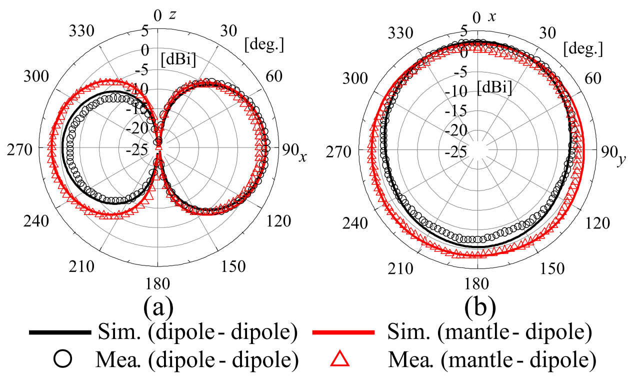


Fig. 14 Comparison of mutual coupling suppression between dipole antenna and mantle cloak antenna in simulated and measured radiation patterns. (a) zx-plane, (b) xy-plane.

4. Conclusion

A square rod mantle cloak antenna with a rejection band on the low-frequency side of the operating frequency was proposed and demonstrated to suppress mutual coupling with closely placed antennas. The square rod dipole antenna was covered with a high-dielectric substrate, and strip conductors were placed at the center of each side of the antenna. Additionally, a copper rod was placed in space to match the antenna feeding point. Similar to the cylindrical mantle cloak antenna in previous studies [8, 9], the designed antenna exhibits a rejection band at 720 MHz and an operating frequency of 750 MHz. The designed antenna was fabricated and measured, and the results were consistent with the simulation results. The designed square rod mantle cloak antenna was found to suppress the mutual coupling owing to the cloaking effect of the transmission characteristics and electric field distribution.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP21K04055.

References

[1] N. Kuga and H. Arai, "Method of suppressing the mutual coupling between two inverted F antenna," *IEICE Trans. Commun.*, vol. J77-B-II, no. 1, pp. 44–46, Jan. 1994.

[2] H. Sato, Y. Koyanagi, K. Ogawa, and M. Takahashi, "Method of dual-frequency decoupling for closely spaced two small antennas," *IEICE Trans. Commun.*, vol. J94-B, no. 9, pp. 1104–113, Sept. 2011.

[3] A.C.K. Mak, C.R. Rowell, and R.D. Murch, "Isolation enhancement between two closely packed antennas," *IEEE Trans. Antennas Propag.*, vol. 56, no. 11, pp. 3411–3419, Nov. 2008. DOI: 10.1109/tap.2008.2005460

[4] Y.R. Padooru, A.B. Yakovlev, P.-Y. Chen, and A. Alù, "Analytical modeling of conformal mantle cloaks for cylindrical objects using sub-wavelength printed and slotted arrays" *J. Appl. Phys.* vol. 112, 034907, Aug. 2012. DOI: 10.1063/1.4745888

[5] A. Alù, "Mantle cloak: Invisibility induced by a surface," *Phys. Rev. B*, vol. 80, no. 24, 245115, Dec. 2009. DOI: 10.1103/physrevb.80.245115

[6] P.-Y. Chen and A. Alù, "Mantle cloaking using thin patterned metasurfaces," *Phys. Rev. B*, vol. 84, no. 20, 205110, Nov. 2011. DOI: 10.1103/physrevb.84.205110

[7] A. Monti, J. Soric, A. Alù, F. Bilotti, A. Toscano, and L. Vegni, "Overcoming mutual blockage between neighboring dipole antennas using a low-profile patterned metasurface," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1414–1417, Oct. 2012. DOI: 10.1109/lawp.2012.2229102

[8] T. B. Nguyen, K. Sakakibara, N. Michishita, H. Morishita, T. Miyazaki, and M. Tadokoro, "Mantle cloak antenna for reducing mutual coupling at close frequency," 15th Eur. Conf. Antennas Propag., 1570686825, pp1–5, March 2021. DOI: 10.23919/eucap51087.2021.9411110

[9] T. B. Nguyen, H. Hashiguchi, N. Michishita, H. Morishita, T. Miyazaki, and M. Tadokoro, "Mantle cloak antenna with rejection band at lower frequency side of operating frequency," IEEE AP-S Int. Symp., FR-A2.2P.2, pp. 2018–2019 Dec. 2021. DOI: 10.1109/aps/ursi47566.2021.9704688

[10] S. Ozawa, H. Hashiguchi, N. Michishita, H. Morishita, K. Sakimoto, T. Miyazaki, and M. Tadokoro, "Square rod antenna covered by man-

tle cloak with rejection band at lower frequency side of operating frequency," URSI-JRSM, BP-6, p. 141, Sept. 2022.

[11] S. Ozawa, H. Hashiguchi, N. Michishita, H. Morishita, K. Sakimoto, T. Miyazaki, and M. Tadokoro, "Square rod antenna covered by mantle cloak with rejection band at lower frequency side of operating frequency," IEICE General. Conf., B-1-91, March 2023 (in Japanese).