Meta-Antennas: From Academic Research to Industrial Applications of Mobile Terminals

Kunpeng Wei and Aofang Zhang

EDITOR'S NOTE

In this installment of "Industry Activities," Drs. Kunpeng Wei and Aofang Zhang from Honor Device Company discuss how research endeavors undertaken during a Ph.D. program can actually be developed into a successful product later on in one's career. I would like to thank Dr. Jiang Zhu for organizing this.

Rod Waterhouse

Meta-antennas, including mu-near-zero (MNZ) and epsilon-near-zero (ENZ) antennas, have been intensively studied in academia, but very few of them have been applied to industrial products. This article first introduces my career path from academia to industry and then presents some application cases of meta-antennas in mobile terminals, including smartphones, tablets, and routers. I hope that this article can build a bridge between academia and industry and guide the study direction for academic researchers.

CAREER PATH: FROM ACADEMIA TO INDUSTRY

Unlike the fascinating career paths by J. Anguera [1] and C.J. Reddy [2], here I focus on the innovative applications of meta-antennas from academic studies to mobile terminals. In 2008, this story began with my pursuit of a Ph.D. degree from Tsinghua University, Beijing, China, in the field of microwave and antenna technology and under the supervision of Prof. Zhijun Zhang, IEEE Fellow.

Metamaterial was the most popular research direction in electromagnetic fields at that time [3]–[5]. In the influence of the great success of my mentor Prof. Zhang in the field of mobile terminal antennas for Amphenol, Nokia, and Apple, I chose meta-antennas for the application of mobile terminals as my Ph.D. research topic.

The composite right/left-handed transmission line metamaterial, as a kind of metamaterial, including mu-negative and epsilon-negative transmission line metamaterials, has attracted strong interest for many academic researchers, and a lot of studies have been done to explore its potential applications [6]–[11]. In particular, MNZ and ENZ antennas, working at the zeroth-order-resonance of the mu-negative and epsilon-negative transmission line metamaterials, have the characteristics of infinite wavelength and uniform distributed magnetic/electric field, and I found them to be capable of realizing many novel functions [9]–[11]. For example, I constructed a metaline antenna in [9] through periodically loaded parallel-plate lines, which could be able to achieve a wide impedance bandwidth with a stable omnidirectional radiation pattern. In addition, the metaloop antenna in my works [10], [11], consisting of a loop with periodical capacitive loadings, could be capable of generating a horizontally polarized omnidirectional radiation pattern.

I completed my Ph.D. degree successfully in five years' time with four articles in *IEEE Transactions on Antenna Propagation* and four articles in *IEEE Antennas and Wireless Propagation Letters*, which were mostly focused on metaline and metaloop antennas. Once my Ph.D. work was completed, due to the doubts about the application of meta-antenna technologies in industry at that time, I left the mobile terminal business for two years.

From July 2013 to December 2015, I was employed in the Radar Research Institute of the Chinese Air Force Research Laboratory, conducting research in the areas of phased-array antenna design and radar system design.

Digital Object Identifier 10.1109/MAP.2022.3179894
Date of current version: 5 August 2022

In January 2016, the Consumer Business Group of Huawei Inc. invited me as an antenna specialist to continue the research of smartphone antennas. I was fortunate enough to lead Huawei's Xi'an Antenna Team for the Huawei Nova series and Honor brand smartphones. I mainly designed the antennas in the Huawei P20lite, Mate20lite, P30lite, Mate30lite, Honor magic2, Honor20 series, and Honor30 series. In 2021, I joined Honor Device Co. Ltd. when this company split from Huawei, and I am currently the director of the Honor Antenna Team.

Our team at Honor has found that meta-antennas have many valuable applications in mobile terminals in recent years, including but not limited to smartphones, tablets, laptops, and routers. This article briefly introduces some applications of meta-antennas that have been applied to mobile terminals.

APPLICATIONS FOR MOBILE TERMINALS

Since 2017, consumers' pursuit of the ultimate screen-to-body ratio for smartphones makes antenna design increasingly challenging for antenna engineers because the antenna clearance is getting smaller and smaller, which would inevitably deteriorate antenna performance, such as reducing the antenna efficiency and narrowing the antenna bandwidth. To overcome the degradation of the antenna performance and cover more frequency bands, such as from 1,710 to 2,690 MHz (bands 1/2/3/4/7/38/39/40/41, and so forth), we started to use antenna tuners to tune the operating frequency band electrically at first. However, in real engineering applications, this method may reduce the reliability of the antennas, increase the cost of the antennas, and introduce a large insertion loss.

> **Inspired by the MNZ antenna in my work, our team designed an ENZ antenna, as the second type of metaline antenna, to be applied to tablets.**

From 2020, I started to lead my antenna team to develop antenna technologies, with the purpose of making the wireless communication performance of our mobile terminals more competitive. At this time, I set a goal for myself. Is it possible to make the antenna cover all the frequency bands from 1,710 to 2,690 MHz in a small antenna clearance without using extra antenna tuners? Fortunately, my team and I found that the MNZ antenna, as the first type of metaline antenna in my work [9], has a higher antenna efficiency and wider bandwidth than traditional antennas, and then such an MNZ antenna was employed in the smartphone shown in Figure 1(a) without using extra antenna tuners to replace the traditional tuner-based antennas.

The structure of the MNZ antenna is demonstrated in Figure 1(b), where multiple capacitive loadings are added in the

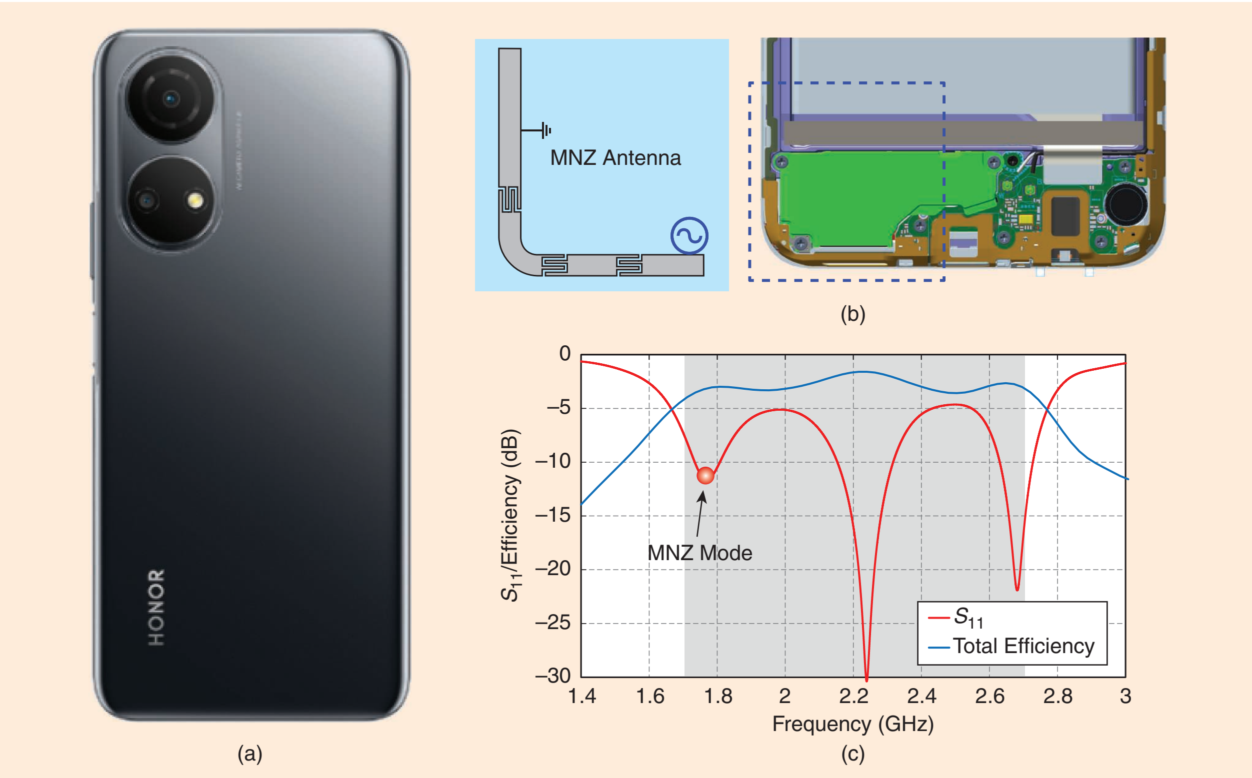

FIGURE 1. (a) An application for smartphones. (b) The structure of the MNZ antenna inside the smartphone. (c) The S11 and antenna efficiency of the MNZ antenna working from 1,710 to 2,690 MHz.

middle of the antenna. In such an antenna design, the values and realization methods of the capacitive loadings play a key role in the antenna performance to obtain the MNZ mode with a uniform distributed surface current. It can be observed in Figure 1(c) that the MNZ antenna could cover the required frequency range from 1,710 to 2,690 MHz without using extra antenna tuners.

Mobile terminal antenna engineers often face the problem that the emitted power has to be backed off due to the specific absorption rate (SAR) limitation, which leads to the deterioration of wireless communication performance, even if the passive performance of the antenna is well designed. SAR represents the radiation of the antenna to the user's body, which has a stricter standard for tablets than smartphones.

Inspired by the MNZ antenna in my work [9], our team designed an ENZ antenna, as the second type of metaline antenna, to be applied to tablets, as shown in Figure 2(a), with very low SAR performance. The structure of the ENZ antenna is demonstrated in Figure 2(b), where multiple inductances are added in parallel between the radiating branch and the metallic ground. With a proper design of the inductances, the SAR of such an antenna could be greatly decreased with a uniform distributed electric field, and the SAR hotspot is demonstrated in Figure 2(c).

Apart from metaline antennas, our team also found that the metaloop antennas in my works [10], [11] are very suitable for the radiation pattern requirements of Wi-Fi routers, and thus, such metaloop antennas were employed in the bucket-shaped router, as shown in Figure 3(a). The antenna configuration inside the bucket-shaped router is shown in Figure 3(b) and (c), where the 2 × 2 multiple-input, multiple-output antenna system, working at the Wi-Fi 5G band, is formed by a dipole antenna and an MNZ loop antenna. The MNZ loop antenna could be capable of generating a similar radiation pattern as the dipole antenna but with an orthogonal polarization, and thus, a bucket-shaped router with polarization diversity performance could have a more stable signal connection with an arbitrarily rotated smartphone than other types of antenna systems.

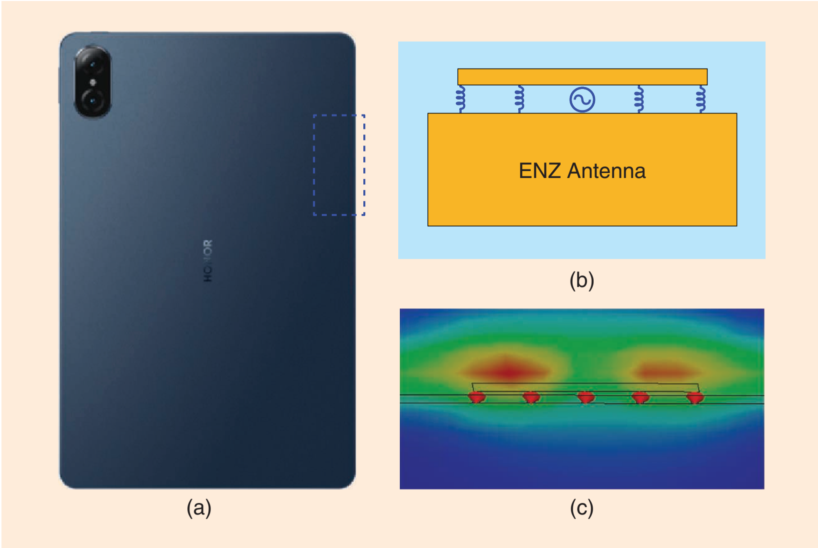

FIGURE 2. (a) An application for tablets. (b) The structure of the ENZ antenna. (c) SAR hotspot.

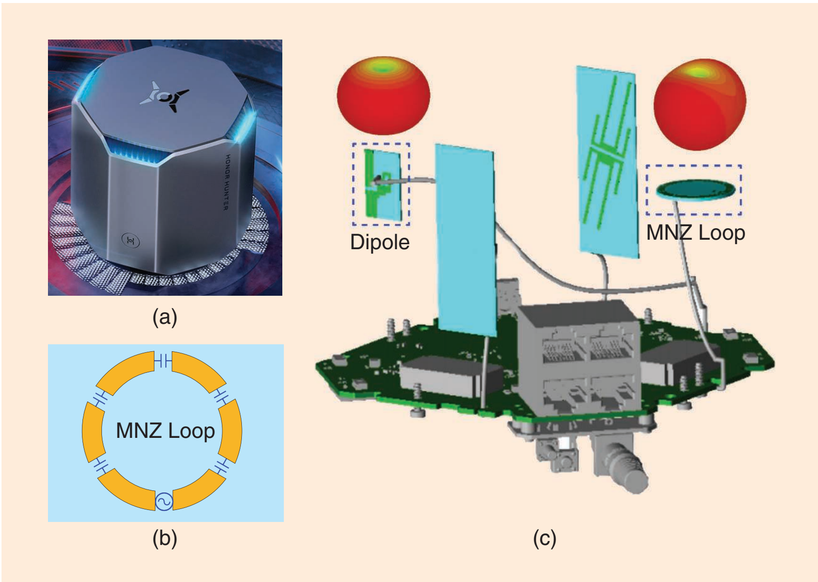

FIGURE 3. (a) An application for bucket-shaped routers. (b) The structure of the MNZ loop antenna. (c) The antenna configuration inside the bucket-shaped router.

CONCLUSIONS

I have introduced some industrial application cases of metaline and metaloop antennas that have been applied to smartphones, tablets, and bucket-shaped routers. In addition to the aforementioned applications, there are also many other applications that have been discovered by our Honor Antenna Team, and we are still further exploring the potential applications of meta-antennas to improve the wireless communication performance of mobile terminals, including but not limited to smartphones, laptops, tablets, and routers.

I hope that this article can guide the study direction for the IEEE community's researchers and build a bridge between academia and industry. I also hope that this article can inspire engineers to discover more valuable academic studies to apply to industrial products.

ACKNOWLEDGMENTS

I would like to thank the members of my Honor Antenna Team for their contributions to the development of antenna technologies and the market success of Honor's products.

AUTHOR INFORMATION

Kunpeng Wei (weikunpeng2@hihonor.com) is the director of the Antenna Team with Honor Device Co. Ltd., Beijing, 100095, China. He has authored more than 50 refereed papers on consumer electronics antenna design. He is a Senior Member of IEEE.

Aofang Zhang (zhangaofang@hihonor.com) is the senior antenna expert with Honor Device Co. Ltd., Xi'an, 710000, China. His current research interests include metamaterial antennas, small-size antennas, and multiple-input, multiple-output antennas in mobile terminals. He is a Member of IEEE.

REFERENCES

[1] J. Anguera and A. Andujar, "Antenna booster technology: From R&D to Ignion [Industry Activities]," *IEEE Antennas Propag. Mag.*, vol. 63, no. 4, pp. 133–137, Aug. 2021, doi: 10.1109/MAP.2021.3085163.
[2] C. Reddy, "Career path: From researcher to entrepreneur and beyond," *IEEE Antennas Propag. Mag.*, vol. 63, no. 2, pp. 111–116, Apr. 2021, doi: 10.1109/MAP.2021.3054881.
[3] D. R. Smith, W. J. Padilla, D. Vier, S. C. Nemat-Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett.*, vol. 84, no. 18, p. 4184, 2000, doi: 10.1103/PhysRevLett.84.4184.
[4] J. B. Pendry, D. Schurig, and D. R. Smith, "Controlling electromagnetic fields," *Science*, vol. 312, no. 5781, pp. 1780–1782, 2006, doi: 10.1126/science.1125907.
[5] D. Schurig *et al.*, "Metamaterial electromagnetic cloak at microwave frequencies," *Science*, vol. 314, no. 5801, pp. 977–980, 2006, doi: 10.1126/science.1133628.
[6] A. Lai, T. Itoh, and C. Caloz, "Composite right/left-handed transmission line metamaterials," *IEEE Microw. Mag.*, vol. 5, no. 3, pp. 34–50, Sep. 2004, doi: 10.1109/MMW.2004.1337766.
[7] A. Sanada, C. Caloz, and T. Itoh, "Characteristics of the composite right/left-handed transmission lines," *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 2, pp. 68–70, Feb. 2004, doi: 10.1109/LMWC.2003.822563.
[8] A. Sanada, M. Kimura, I. Awai, C. Caloz, and T. Itoh, "A planar zeroth-order resonator antenna using a left-handed transmission line," in *Proc. 34th 2004 Eur. Microw. Conf.*, vol. 3, pp. 1341–1344.
[9] K. Wei, Z. Zhang, Z. Feng, and M. F. Iskander, "A wideband MNG-TL dipole antenna with stable radiation patterns," *IEEE Trans. Antennas Propag.*, vol. 61, no. 5, pp. 2418–2424, May 2013, doi: 10.1109/TAP.2013.2241717.
[10] K. Wei, Z. Zhang, and Z. Feng, "Design of a wideband horizontally polarized omnidirectional printed loop antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 49–52, Jan. 2012, doi: 10.1109/LAWP.2012.2182670.
[11] K. Wei, Z. Zhang, Z. Feng, and M. F. Iskander, "A MNG-TL loop antenna array with horizontally polarized omnidirectional patterns," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 2702–2710, Jun. 2012, doi: 10.1109/TAP.2012.2194643.
[12] D. M. Pozar, *Microwave Engineering*. Hoboken, NJ, USA: Wiley, 2011.