A Comparative Study on Dual-Polarized Wideband Segmented Loop Antenna for Mobile Platforms using Different Substrates

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***Abstract*—The requirements of mobile antennas became more complex with the evolution of new high-speed mobile communication and data transmission. To overcome the multipath effect and increase channel capacity for next-generation mobile platforms, the mobile antenna requires different radiation patterns. The wideband segmented loop antenna satisfies the requirements of mobile antennas. The Wideband segmented loop antenna produces horizontally and vertically polarized omnidirectional patterns. The planar double segmented loop antenna element produces one of the modes with a horizontally polarized pattern. The loop element excites the ground plane and produces the other mode with a vertically polarized pattern. These resonant modes are combined with adjacent resonant frequencies for wideband applications. The wideband segmented loop antenna has a bandwidth of 710 MHz. A comparison between wideband segmented loop antenna made of three different substrates (Flame Retardant 4 (FR4), Bakelite, Rogers 4003) show that as the relative permittivity of the substrate decreases the resonant frequencies shift to the right and the radiation patterns show that the gain is also related to relative permittivity of the substrate. High-Frequency Structure Simulator (HFSS) was used for simulation results.**

***Index Terms*—Broadband antenna, mobile antenna, segmented loop antenna, omnidirectional antenna, dual polarization, multi-mode.**

I. Introduction

The mobile antennas have advanced fastly during the past decade with the evolution in mobile communication technologies. The speed of mobile communications and data transmissions are increasing day by day. This makes the mobile antenna structure more complex [1]. To overcome the multipath effect and increase channel capacity for next-generation mobile platforms the mobile antenna requires different radiation patterns [2], [3].

Most of the existing mobile antenna act as electric dipoles and have vertically polarized patterns [1]. To produce horizontally polarized omnidirectional pattern a new antenna, planar segmented loop antenna has been designed. This type of antenna is best for mobile platforms, because it is a simple structure. The disadvantage of this system is the narrow bandwidth, this is due to the segmented loops are shortened to meet the size limitation of mobile platforms [4]— [6]. Then developed a broadband dual-polarized omnidirectional antenna but it is not fit for mobile platforms, due to the large volume and distance of the two individual radiation elements [7]. The wideband segmented loop antenna satisfies the requirements of mobile antennas.

The performance of the antenna depends on the ground plane, which is a large piece of metal around the antenna element. In loop type antenna the ground plane is used to increase bandwidth and efficiency. The ground plane in mobile antennas introduce additional resonant modes to increase bandwidth [8], [9].

In this work, we compared dual-polarized wideband segmented loop antenna for mobile platforms made of three substrates(FR4, Bakelite, Rogers 4003). In dual-polarized wideband segmented loop antenna, the horizontally polarized pattern is produced by the double segmented loop element, while the vertically polarized pattern is produced by the ground plane excited by the loop element. The wideband segmented loop antenna has two resonant frequencies and has a bandwidth of 710 MHz.

II. Properties of dielectric substrates

A. FR-4 or (FR4) Gloss Epoxy

FR4 is a grade designation of glass reinforced epoxy laminate material. FR4 is a composite material made of woven fiberglass cloth with an epoxy resin binder which is self-extinguishing(flame resistant). FR be an abbreviation of flame retardant. FR-4 glass epoxy is an in demand and versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios. FR-4 is most commonly used as an electrical insulator having substantial mechanical strength with near zero water absorption. FR4 epoxy has a relative permittivity(ε_r) of 4.4 and relative permeability (μ_r) of 1.

B. Bakelite

Bakelite is an early plastic. It is formed by an elimination reaction of phenol with formaldehyde, hence it is known as thermosetting phenol formaldehyde resin. It is mainly used as an electrical insulator having substantial mechanical strength. Bakelite has a relative permittivity(ε_r) of 4.8 and relative permeability(μ_r) of 1.

C. Rogers 4003

RO4003 Series High-Frequency Circuit Materials are glass reinforced hydrocarbon/ceramic laminates (Not PTFE) designed for high volume and performance sensitive commercial applications. To offer superior high frequency performance and low-cost circuit fabrication, RO4000 laminates are designed. The out-turn is a low loss material which can be fabricated using standard epoxy/glass (FR4) processes provided at competitive prices. Rogers 4003 has a relative permittivity(ε_r) of 3.55 and relative permeability (μ_r) of 1.

III. Antenna design

The geometry of the dual-polarized wideband segmented loop antenna is shown in Fig. 1 and 2. The proposed antenna composed of a loop antenna element and a ground plane, so we can say it is a simple structure.

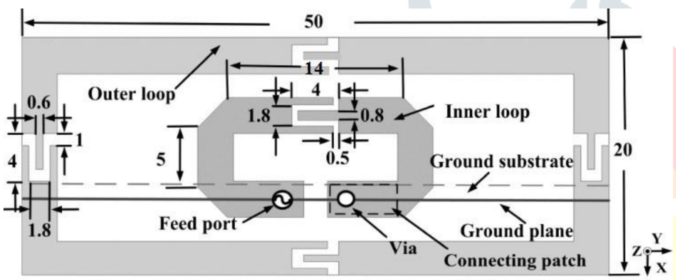

Fig. 1. Antenna geometry top view.

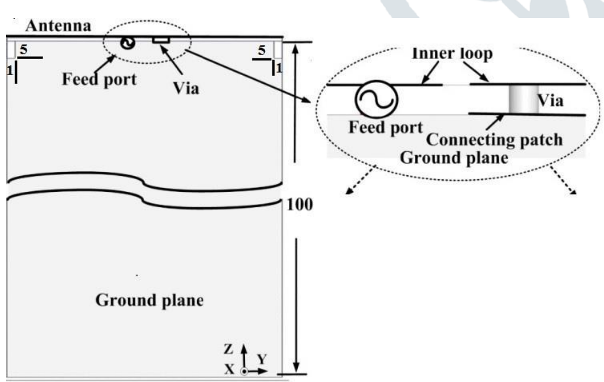

Fig. 2. Antenna geometry side view.

The loop element is engraved on the substrate(FR4, Bakelite, Rogers 4003)and has a length of 50 mm, breadth of 20 mm and thickness of 1 mm and the loop element has a planar configuration. The ground plane is also engraved on the substrate(FR4, Bakelite, Rogers 4003) and has a length of 100 mm, breadth of 50 mm and thickness of 1 mm. The antenna structure has two segmented loop elements and indicates them as inner loop and outer loop. The inner loop has a length of 20 mm, a breadth of 10 mm and width of 3 mm. It is connected to the feed port at one end and another end is connected to the ground plane through a cylinder with a radius of 0.5 mm and a connecting patch of length 6 mm and breadth 3 mm. The middle portion of the inner loop consists of an interdigital capacitor with an area of 4 mm x 3 mm. The outer loop be all around the inner loop has a length of 50 mm, breadth of 20 mm and a width of 3 mm and contain four interdigital capacitors. Two small rectangles of length 5 mm and breadth 1 mm is removed from the ground plane from the two ends along with the breadth of the ground plane.

In this antenna structure, a planar double segmented loop antenna element produces one mode with a horizontally polarized pattern. The other mode with a vertically polarized pattern is produced by the ground plane due to the excitation caused by the loop element. This can be used for the wideband application because the produced resonant modes combined with the adjacent resonant frequencies [10].

IV. results

Results of wideband segmented loop antenna made of FR4, Bakelite, Rogers 4003 substrates are compared here.

A. S_{11} Parameter

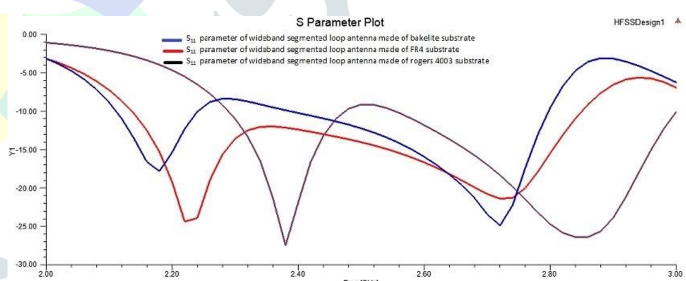

Fig. 3. S-parameter plot of wideband segmented loop antennas made of Bakelite, FR4, Rogers 4003.

Fig. 3 represents S-parameter plot of wideband segmented loop antennas made of Bakelite, FR4, Rogers 4003. From the graphs, it can be seen that wideband segmented loop antenna made of Bakelite has its resonant modes at 2.16 GHz and 2.7 GHz. Wideband segmented loop antenna made of FR4 substrate has its resonant modes at 2.2 GHz and 2.8 GHz. The resonant modes of the wideband segmented loop made of Rogers 4003 substrates are at 2.38 GHz and at 2.86 GHz. The relative permittivity(ε_r) of Bakelite is 4.8, ε_r of FR4 is 4.4 and ε_r of Rogers 4003 is 3.55. From the graph, it is clear that as the relative permittivity(ε_r) decreases the resonant frequencies shift to the right.

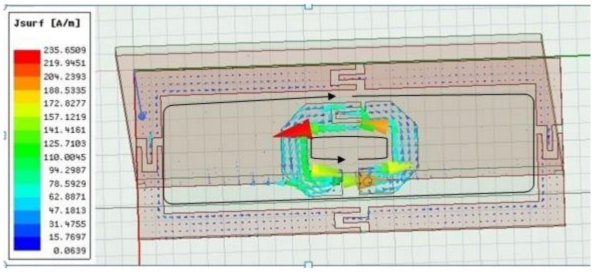

Fig. 4. The current distribution of segmented loop at 2.2 GHz.

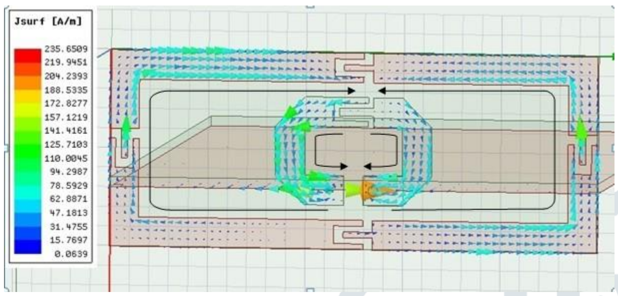

Fig. 5. The current distribution of segmented loop at 2.8 GHz.

B. Current Distribution

Fig. 4 and 5 depict the current distribution of wideband segmented loop antenna made of FR4 substrate at 2.2 GHz and 2.8 GHz. The black arrow indicates the direction of current flow. At 2.2 GHz the current on both inner and outer loop has a single flowing direction, but the direction of current is opposite. This is due to the reason the outer loop is magnetically coupled and excited by the inner loop. To introduce additional capacitance into the loops and compensate phase delay of current to form a zero-phase-shift line at 2.2 GHz. At 2.8 GHz the currents on the inner loop and outer do not have single flowing direction and distribute out of phase. It is due to the first order resonance of a one wavelength loop which shows a π phase shift around the perimeter of the loop.

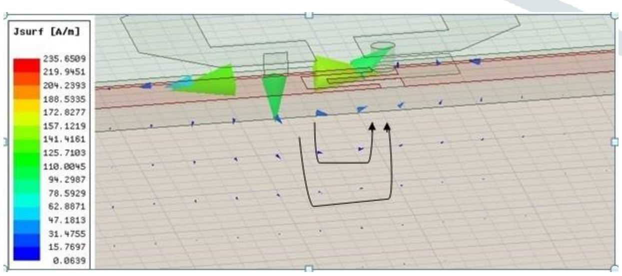

Fig. 6. The current distribution of ground plane at 2.2 GHz.

Fig 6 and 7 show the current distribution on the ground plane at 2.2 GHz and 2.8 GHz. At 2.2 GHz the current flows from the feed port to the connecting patch and has single flowing direction. The current at 2.2 GHz does not excite

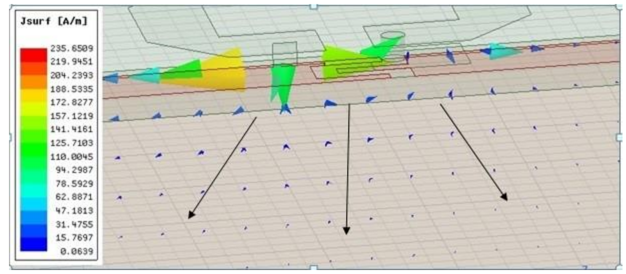

Fig. 7. The current distribution of ground plane at 2.8 GHz.

the vertically polarized radiation mode on the ground plane effectively. At 2.8 GHz the current flows away from the feed port and connecting patch and excites strongly the vertically polarized radiation mode on the ground plane [10].

C. 3D Radiation Patterns

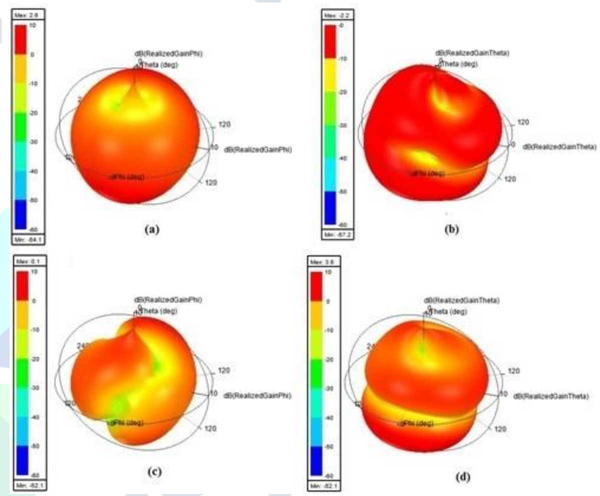

Fig. 8. Simulated 3D radiation patterns of wideband segmented loop antenna made of FR4 substrate. (a) Horizontally polarized pattern at 2.2 GHz. (b) Vertically polarized pattern at 2.2 GHz. (c) Horizontally polarized pattern at 2.8 GHz. (d) Vertically polarized pattern at 2.8 GHz.

The simulated 3D radiation patterns of wideband segmented loop antenna made of FR4 substrate are shown in Fig. 8. It can be seen that at 2.2 GHz the horizontally polarized omni-directional pattern has more gain(2.6 dB) than the vertically polarized omnidirectional pattern (-2.2 dB). Similarly at 2.8 GHz the vertically polarized omnidirectional pattern has more gain(3.6 dB) than the horizontally polarized omnidirectional pattern(0.1 dB). The reason for this is already explained in the previous section.

The simulated 3D radiation patterns of wideband segmented loop antenna made of Bakelite substrate are shown in Fig. 9. It can be seen that at 2.2 GHz the horizontally polarized omnidirectional pattern has more gain(2.8 dB) than the vertically polarized omnidirectional pattern (-3.3 dB). Similarly at 2.8 GHz the vertically polarized omnidirectional pattern has more

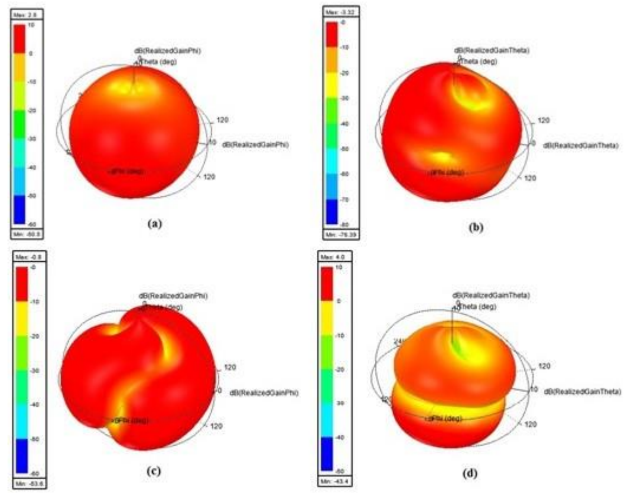

Fig. 9. Simulated 3D radiation patterns of wideband segmented loop antenna made of Bakelite substrate. (a) Horizontally polarized pattern at 2.2 GHz. (b) Vertically polarized pattern at 2.2 GHz. (c) Horizontally polarized pattern at 2.8 GHz. (d) Vertically polarized pattern at 2.8 GHz.

gain(4 dB) than the horizontally polarized omnidirectional pattern(-0.8 dB).

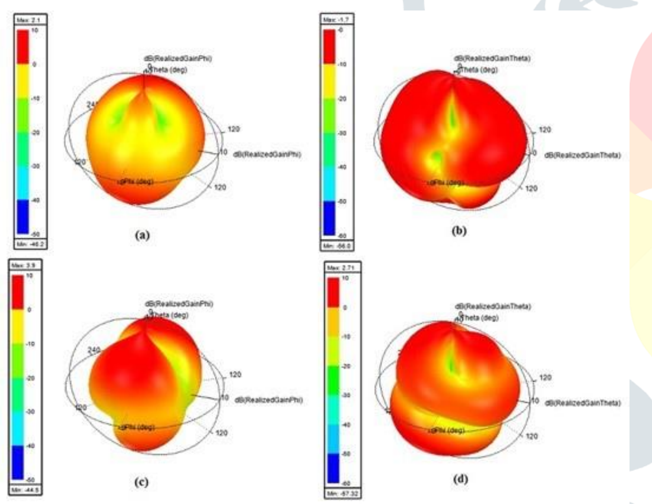

Fig. 10. Simulated 3D radiation patterns of wideband segmented loop antenna made of Rogers 4003 substrates. (a) Horizontally polarized pattern at 2.2 GHz. (b) Vertically polarized pattern at 2.2 GHz. (c) Horizontally polarized pattern at 2.8 GHz. (d) Vertically polarized pattern at 2.8 GHz.

The simulated 3D radiation patterns of wideband segmented loop antenna made of Rogers 4003 substrates are shown in Fig. 10. It can be seen that at 2.2 GHz the horizontally polarized omnidirectional pattern has more gain(2.1 dB) than the vertically polarized omnidirectional pattern (-1.7 dB). At 2.8 GHz horizontally polarized omnidirectional pattern(3.9 dB) has more gain than the vertically polarized omnidirectional pattern (2.71 dB).

At frequency 2.2 GHz the horizontally polarized omnidirectional pattern gain increases as the relative permittivity of substrates increase, at the same time the vertically polarized pattern gain decreases with an increase in relative permittivity of the substrate. But at frequency 2.8 GHz the vertically polarized omnidirectional pattern gain increases with the increase in relative permittivity of substrates, meanwhile, the horizontally polarized pattern gain decreases with an increase in relative permittivity of the substrates.

D. 2D Radiation Patterns

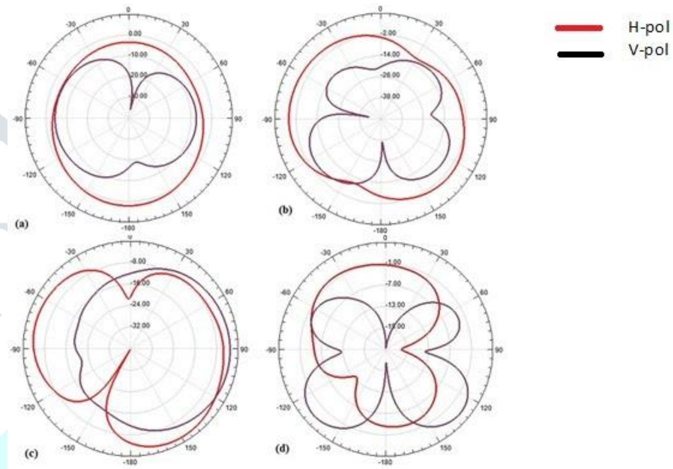

Fig. 11. Simulated 2D radiation patterns of wideband segmented loop antenna made of FR4 substrate. (a) XY plane radiation patterns at 2.2 GHz. (b) XZ plane radiation patterns at 2.2 GHz. (c) XY plane radiation patterns at 2.8 GHz. (d) XZ plane radiation patterns at 2.8 GHz.

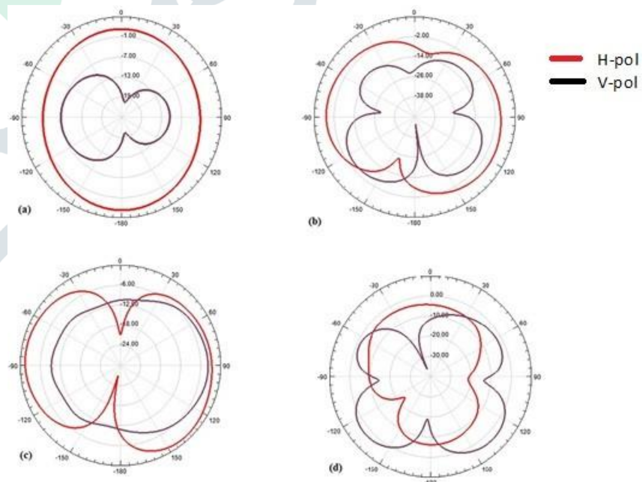

Fig. 12. Simulated 2D radiation patterns of wideband segmented loop antenna made of Bakelite substrate. (a) XY plane radiation patterns at 2.2 GHz. (b) XZ plane radiation patterns at 2.2 GHz. (c) XY plane radiation patterns at 2.8 GHz. (d) XZ plane radiation patterns at 2.8 GHz.

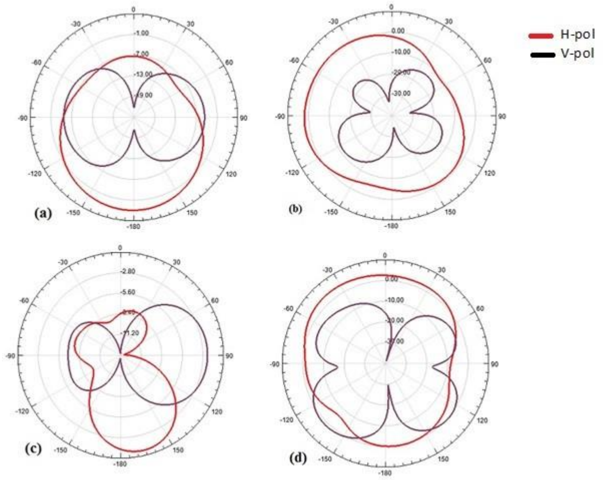

Fig. 13. Simulated 2D radiation patterns of wideband segmented loop antenna made of Rogers 4003 substrates. (a) XY plane radiation patterns at 2.2 GHz. (b) XZ plane radiation patterns at 2.2 GHz. (c) XY plane radiation patterns at 2.8 GHz. (d) XZ plane radiation patterns at 2.8 GHz.

Fig. 11 (a) and (c) represent the radiation patterns of the wideband segmented loop antenna made of FR4 substrate in the XY plane at 2.2 GHz and 2.8 GHz. Fig. 11 (b) and (d) represent the radiation patterns in the XZ plane at 2.2 GHz and 2.8 GHz. Fig. 12 (a) and (c) represent the radiation patterns of the wideband segmented loop antenna made of Bakelite substrate in the XY plane at 2.2 GHz and 2.8 GHz. Fig. 12 (b) and (d) represent the radiation patterns in the XZ plane at 2.2 GHz and 2.8 GHz. Fig. 13 (a) and (c) represent the radiation patterns of the wideband segmented loop antenna made of Rogers 4003 substrates in the XY plane at 2.2 GHz and 2.8 GHz. Fig. 13 (b) and (d) represent the radiation patterns in the XZ plane at 2.2 GHz and 2.8 GHz.

V. Conclusion

Designed and compared wideband segmented loop antenna made of different substrates (FR4, Bakelite, Rogers 4003). In this antenna structure, one mode with a horizontally polarized pattern was produced by a planar double segmented loop antenna element. The other mode with a vertically polarized pattern is produced by the ground plane which is excited by the loop element. The resonant modes produced by the loop elements and the ground plane are combined for wideband applications. From the simulated S11 parameter graph it clear that there are two resonant frequencies. The wideband segmented loop antenna made of FR4 substrate has a bandwidth of 710 MHz from 2.14 GHz to 2.85 GHz, while the antenna made of Bakelite has the same bandwidth from 2.11 GHz to 2.82 GHz and the antenna made of Rogers 4003 also has the same bandwidth from 2.29 GHz to 3 GHz. The comparison results imply that as the relative permittivity of the substrate decreases the resonant frequencies shift to the right, however, the bandwidth remains the same. The radiation patterns show that the gain is also related to relative permittivity of the substrate.

References

[1] Z. J. Zhang, *Antenna Design for Mobile Devices*. Singapore: Wiley, 2011.

[2] H. Li, Y. Tan, B. K. Lau, Z. N. Ying, and S. He, "Characteristic mode based tradeoff analysis of antenna-chassis interactions for multiple antenna terminals," *IEEE Trans. Antennas Propag.*, vol. 60, no. 2, pp. 490–502, Feb. 2012.

[3] P. Mattheijssen, M. Herben, G. Dolmans, and L. Leyten, "Antenna pattern diversity versus space diversity for use at handhelds," *IEEE Trans. Veh. Technol.*, vol. 53, no. 4, pp. 1035–1042, Jul. 2004.

[4] J. Shi, X. M. Qing, Z. N. Chen, and C. K. Goh, "Electrically large dual-loop antenna for UHF near–field RFID reader," *IEEE Trans. Antennas Propag.* , vol. 61, no. 3, pp. 1019–1025, Mar. 2013.

[5] D. Kajfez, A. Z. Elsherbeni, V. Demir, and R. Hasse, "Omnidirectional square loop segmented antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 846–849, Oct. 2016.

[6] J. Shi, X. Wu, X. M. Qing, and Z. N. Chen, "An omnidirectional circularly polarized antenna array," *IEEE Trans. Antennas Propag.*, vol. 64, no. 2, pp. 574–581, Feb. 2016.

[7] X. L. Quan and R. L. Li, A broadband dual-polarized omnidirectional antenna for base stations, *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 943947, Feb. 2013.

[8] O. Cho, H. Choi, and H. Kim, "Loop-type ground antenna using capacitor,"*Electron. Lett.*, vol. 47, no. 1, pp. 11–12, Jan. 2011.

[9] C. Suarez-Fajard, J. O. Gomez-Sara, and M. Ferrando-Bataller, Broad-band PIFA with capacitive feed,*in Proc. APSURSI*, 2009, pp. 14.

[10] Xing Zhao, Bu Ning Tian, Swee Ping Yeo,and Ling Chuen Ong, Wideband segmented loop antenna with dual - polarized Omnidirectional patterns for mobile platforms ,*IEEE Trans. Antennas Propag.*, vol. 65, no. 2, pp. 883−886, Feb. 2017.