Progress In Electromagnetics Research Letters, Vol. 74, 17–22, 2018

A Low Elevation Angle Conical Beam Antenna for CAPS-Based Vehicle Monitoring System

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Abstract—A new C-band monopole antenna is proposed for use in a CAPS-based vehicle monitoring system. This monopole antenna has highly omnidirectional main beam with low elevation angle and sufficient half-power beamwidth by using a cone-shaped ground plane. The impedance bandwidth defined by 10 dB return loss is 650 MHz (5.50–6.15 GHz), and the main beam elevation angle and half-power beamwidth are about 20° and 44° at the operating frequency 5.885 GHz, respectively. The manufactured prototype has survived a long-distance terrestrial test across China, and the design requirements for the satellite link budget, volume, cost, etc. have been reached.

1. INTRODUCTION

Existing global navigation satellite systems (GNSS), such as GPS and GLONASS, can provide navigation, localization and time services except for telecommunication service. During recent years, integration of navigation and telecommunication on signal level has become a reality [1–3]. Chinese Area Positioning System (CAPS) is such an integrated system, which exploits communication satellites on the geostationary orbit (GEO) for both navigation and telecommunication functionalities. A domestic low bitrate communication system based on CAPS plays an important role in ground vehicle monitoring. This monitoring system consists of GEO satellites, earth stations and vehicle terminals. Through the satellites the ground terminals can send real-time trajectory data to the earth station, and the earth station can process the received data and send positioning as well as communication data back to the terminals on the other way around. The operational principle of the CAPS-based vehicle monitoring system is illustrated in Fig. 1.

In this article, we focus on designing a terminal antenna that is a key component in the CAPS-based vehicle monitoring system. CAPS Sat.4 is used in the terrestrial test from Beijing to Xinjiang across the north and west of China, which has an elevation angle varying from 15° to 36°. Therefore, a low elevation angle and azimuth omnidirectional conical beam is required of the proposed antenna, for a low-cost solution without using any servo track equipment.

Conical beam control techniques can be found in a few papers. It is reported in [4, 5] that quadrifilar helical antennas produce conical beams, and the maximum gain direction can be controlled by adjusting the arm length or antenna height. Low-profile loop antennas can also produce conical beams by a few feeding and loading techniques even over a wide band [6, 7]. However, it is quite difficult to obtain low elevation angle conical beams by above-mentioned antennas. A monopole is a common antenna capable of producing omnidirectional conical beams, whose performance can be improved by changing the shape or characteristics of the ground plane. For example, ground planes in modified solid or in defected shape [8–11] are used to realize multiple resonances; the electrical bandgap (EBG) [12], fractal or quasi-fractal

Received 24 January 2017, Accepted 28 February 2018, Scheduled 8 March 2018
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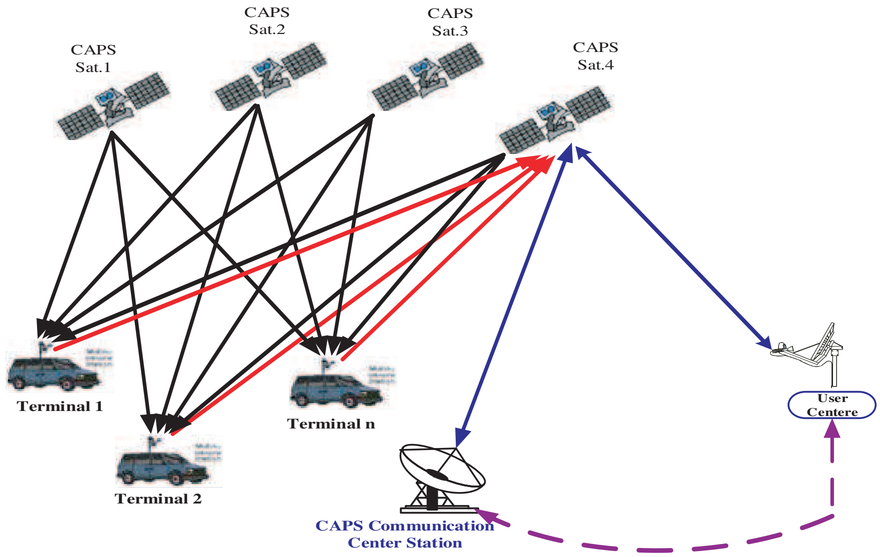


Figure 1. Operational principle of the CAPS experimental system.

[13, 14] and band-notch structures [15] can also be used in the ground plane for bandwidth enhancement, resonance flexibility and miniaturization.

A monopole antenna with a grounding cone is proposed in [16], where the maximum gain direction can readily be adjusted through different aspect angles of the grounding cone. However, the side lobes will increase intensively when the elevation angle of the beam drops lower than 62°; unfortunately, this antenna is unsuitable for CAPS monitoring system including a number of low elevation satellites in space.

2. ANALYSIS AND SIMULATION

The quarter wavelength monopole on a sufficiently large planar ground is the most common type of conventional monopole antennas; its ideal model does not have any side lobe, but the main lobe directs to the horizon (perpendicularly to the zenith axis). The three-quarter monopole otherwise does have side lobe, while its main lobe directs some certain angle relative to the horizon, and the half power beamwidth (HPBW) tends to be adequate for the elevation angle range (15–36°) in this terrestrial test across China. The three-quarter monopole was thus chosen as a starting point for the antenna design.

A cone was introduced on top of a flat ground plane for modifying the direction and beamwidth of the main lobe. The geometry of the proposed antenna is shown in Fig. 2, where L is the length of the rod conductor (radiator); DG is the diameter of bottom ground plane; DU, DL are the diameter of the upper and bottom faces of the cone; H is the cone height. Since DU is fixed as 10 mm for supporting the rod radiator and its dielectric coat, DU and H become key parameters for antenna optimization.

CST Microwave Studio was used to perform the simulations. The performance was investigated around the center frequency 5.885 GHz by sweeping parameters DL and H, respectively. A dielectric coating (POM, $\varepsilon_r = 3.8$) was used for waterproof and anti-corrosion. The diameter of the radiator coat is 10 mm, and the thickness of the ground coat is 2 mm. Figs. 3–4 and Figs. 5–6 show how the S_{11} parameters and radiation patterns vary with the corresponding parameters, respectively.

It can be clearly observed from the parameter sweeps, with the increase of H when other parameters keep constant as in Table 1, that the center resonance point keeps stable, but the bandwidth varies; the beam elevation angle drops while the HPBW varies. With the decrease of DL when other parameters keep constant as in Table 1, both the center resonance point and the bandwidth keep almost stable, and the beam elevation angle drops as well while the HPBW keeps almost unchanged. Notably, the side lobes tend to be suppressed by about 5 dB in the meanwhile. Therefore, it is possible to realize a low elevation angle conical beam by optimizing the key parameters H and DL, as well as to suppress the side lobes by primarily tuning DL. The final optimized antenna dimensions are listed in Table 1.

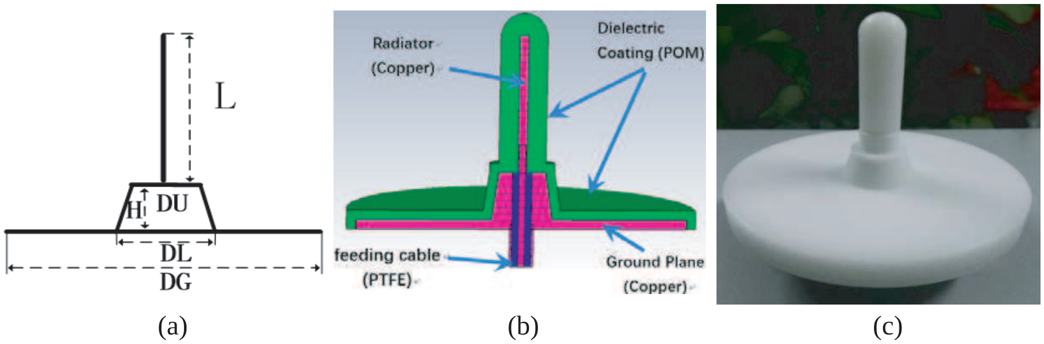


Figure 2. Geometry of the conical ground plane monopole antenna ((a) schematic, (b) model, (c) prototype).

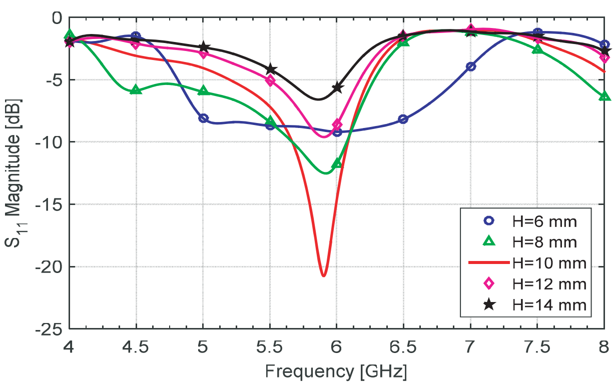


Figure 3. S_{11} sweep by H when others set as in Table 1.

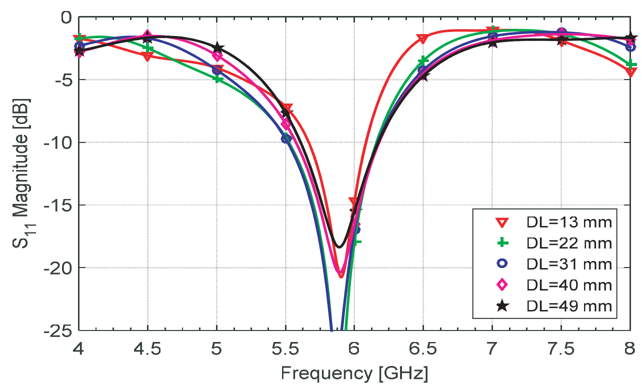


Figure 4. S_{11} sweep by DL when others set as in Table 1.

Table 1. Dimensions of the dielectric-coated monopole antenna.

Parameter	Value
L	29.0 mm
H	10 mm
DU	10 mm
DL	13 mm
DG	70.4 mm

3. MEASURED RESULTS

A prototype of the proposed antenna was manufactured (see Fig. 2). The measured S_{11} and E-plane co-polar pattern are shown in Figs. 7 and 8, respectively. It can be seen that the 10 dB impedance bandwidth covers 5.50–6.15 GHz (about 650 MHz, relative bandwidth 11.2%); the minor discrepancy between the simulated and measured S_{11} is due to the tolerance error of prototype geometry and dielectric constant error of the real coating material. The radiation beam is omnidirectional (φ-invariant) in simulation, and the measured 3-D beam is highly omnidirectional accordingly. The co-polar main beam angle is about 20° relative to the ground ($\theta \approx 70°$), and the HPBW is about 44° at the operating frequency 5.885 GHz, while the relative cross-polar level is lower than -30 dB. The discrepancy between the simulated and measured E-plane patterns is mostly due to the influence of the test table and

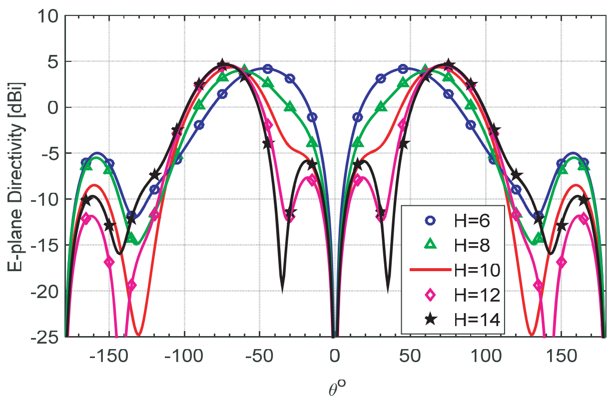


Figure 5. Pattern sweep by H when others set as in Table 1.

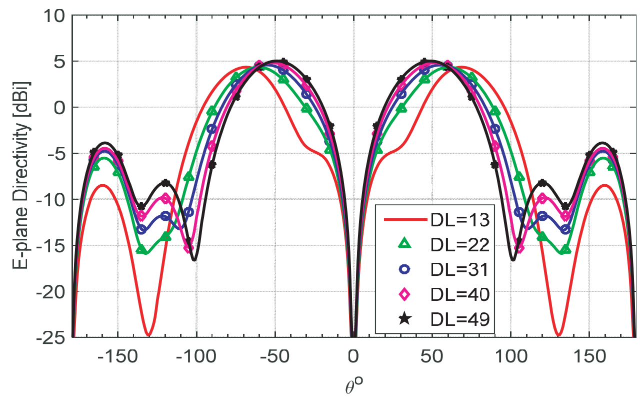


Figure 6. Pattern sweep by DL when others set as in Table 1.

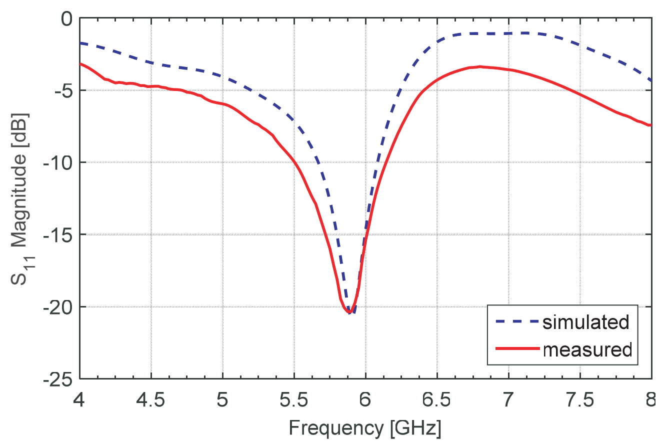


Figure 7. Simulated and measured S_{11} of the antenna prototype.

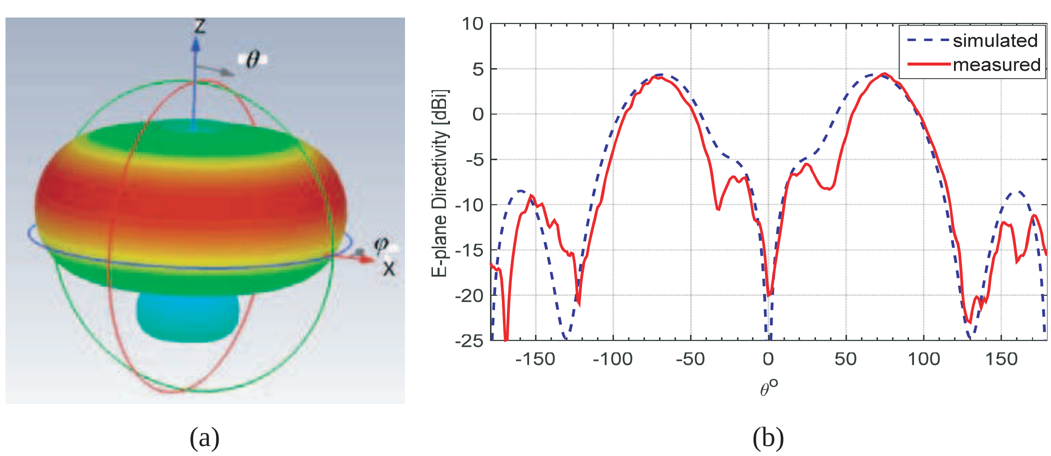
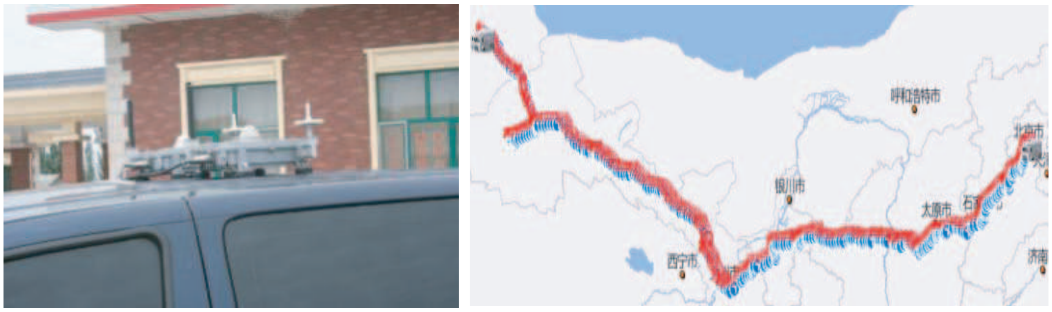


Figure 8. (a) Simulated 3-D beam; (b) simulated and measured E-plane co-polar pattern of the antenna prototype.



(a) (b)

Figure 9. (a) Photo of the vehicle antenna prototype; (b) measured trajectory and map route of the test travel.

accessory tools in the anechoic chamber. Fig. 9(a) shows a photo of the antenna prototype installed together with a CAPS terminal on top of a vehicle, which traveled from Beijing to Xinjiang for the system test in real wild environment. The elevation angle of satellite (CAPS Sat.4) ranged 15–36° (span 21°) along the whole 3000 km journey, and the vehicle often bumped or swung due to various road conditions. Thanks to a sufficient margin of HPBW 44° of the roof antenna, the communication link could still work properly even though maximum gain of the antenna deviated from the satellite direction within about ±20°. It was concluded that the proposed antenna was well functioned and capable of covering the satellite elevation angle range of 15–36° along all the way. As can be seen in Fig. 9(b), the measured trajectory and map route agree very well in a certain scale.

4. CONCLUSION

A C-band monopole antenna with a cone on the ground plane is proposed in this article. This cone-shaped ground is used to adjust the main beam elevation angle and beamwidth of the antenna, in order to satisfy the CAPS link budgets when being installed on a vehicle terminal. Key geometrical parameters were studied and optimized before a prototype was manufactured. The measurement results show that its 10 dB impedance bandwidth ranges from around 5.60 to 6.15 GHz; the main beam elevation angle and the HPBW are about 20° and 44° at 5.885 GHz, respectively. The measurement results agree quite well with the simulation ones. The proposed antenna was tested in a long-distance terrestrial experiment across China and turned out to succeed in meeting the system requirements. The proposed monopole antenna has been finalized for use in the CAPS-based vehicle monitoring system in China.

ACKNOWLEDGMENT

The work was supported by the National Natural Science Foundation of China under Grant No. 11573041 and No. 11603041, and by National Key Research and Development Plan under Grant No. 2016YFB050190403.

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