Design of Compact Active BeiDou Antenna for High-shock Projectile Applications

Xin Ma¹, Xiaochen Chen¹, Li Xiao², Na Wang¹, and Siyang Sun¹(a)

Abstract A novel compact active BeiDou helical antenna, operating at normal mode is proposed for high-shock projectile applications. To achieve excellent impedance matching, a grounded matching stub is introduced in this design. For demonstration, a prototype with extremely compact size (22×22 mm) is fabricated and measured. The measured reflection coefficients below 10 dB is almost 15 MHz centered at 1268 MHz. Omni-directional radiation pattern of the proposed antenna is realized. Additionally, stable signal reception under various motion attitudes could also be proved by experiments.

key words: BeiDou, helical antenna, active antenna, high-shock

Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

Nowadays, with the rapid development of the BeiDou Navigation Satellite System (BDS), it has been widely used in civilian and military fields. The application of BDS in high-shock projectile scenario for accuracy improvement has attracted growing attentions. As an important part of RF link system, the performance of the antenna has an important influence on the overall performance of the electronic device. However, as the installation space becomes smaller and smaller, especially in an artillery fuze for high-shock applications, antenna miniaturization is the only solution. Several effective approaches have been developed to achieve a compact size for GPS/BDS antennas in the past two decades [1-27]. Existing compact BDS/GPS antennas include ceramic patches [1-4], shorting probe loading antennas [5,6], slot-loaded patch and quadruple inverted-F antenna (QIFA) [7-9], leading to antennas as small as λ/9. Nevertheless, due to the insufficient mechanical strength and stiffness, the aforementioned designs are not quite suitable for high-shock projectile applications.

Among the compact circular polarization (CP) antennas, ring patch antennas have received considerable attention because of their physically smaller size as compared to patch antennas [10-21]. In [10], a compact meandered ring patch antenna loaded with four parasitic-grounded patches and a slotted ground is proposed while its overall size is 0.285λ × 0.285λ × 0.035λ, more compact than the square-ring designs in [11-12]. CP operation of annular-ring patch antennas using a pair of inserted slits, two proximity-coupled L-probe feeds and an embedded circular patch are described in [13], [14], [15], respectively. Multiband ring antennas are proposed using nested or stacked structures and coupling feedings [16-21]. Especially, the dual-band dual CP antenna of two eccentric coplanar rings excited by an arc-shaped strip in [16] demonstrates a lower profile than the stacked structures and is structurally simpler than the aperture coupling antennas [17-20]. In [22], a CPW-fed slot antenna is proposed. In [23], a GNSS antenna composed of four U-shape patches shorted to the ground is analyzed. However, these designs are not small enough and are complicated in structure, not suitable for mass production.

There are few literatures about BDS/GPS antenna designs suitable for high-shock projectile applications. The sizes of the conformal antenna arrays which are printed on conical surfaces in [24-27] are still not small enough. In [28], a CP microstrip antenna of small size and CP character conformal with the cross section of a missile is proposed. However, it lacks the ability of wide radiation coverage, hence it is rarely used in practical situations. In [29], an air-borne CP antenna is proposed while it is bulky in volume and complicated in structure. In [30], four inverted-F-type elements are adopted in a compact circular polarized design on artillery projectiles (36×28.6×13.4 mm), while its pattern is almost identical as that of the microstrip patch antenna. However, it is still not small enough, especially in radical direction. More importantly, for BDS applications in high speed aircraft, an omni-directional pattern in broadside of the carrier is preferred in order to stabilize the receiving signals, especially in the application of high-shock projectile. All of the designs mentioned above cannot...
meet this requirement.

This letter reports a novel design of compact active BDS antenna operating at BDS B3 (1.268 GHz) band for high-shock projectile applications. To achieve miniaturization, helical antenna working at normal mode is employed in this paper. To obtain good impedance matching, the grounded matching stub is utilized. By this way, omnidirectional pattern in broadside of the carrier could be achieved, which facilitates the signal reception under various motion attitudes of carrier. Furthermore, a two-staged LNA module is integrated on the ground layer. The overall size of the proposed antenna is only 22 mm in diameter and 22 mm in height, which is quite suitable for installation in an artillery fuze.

2. Antenna design

Figs. 1 (a) and (b) show the side view and planar printed layout of the proposed compact active BDS antenna with geometrical parameters. The antenna mainly consists of a helical antenna and a two-stage LNA module. The single-arm helical antenna loading with a grounded matching stub is fabricated on a cylinder substrate. Note that the fabricated antenna uses Laser-Direct-Structuring (LDS) fabrication processes. The hollow cylinder substrate (h=21 mm, D=9 mm) is mounted on a FR4 board (h=1 mm, εr=4.4, D=22 mm). The cylinder substrate and the FR4 board could be fixed together by using a M2 screw. Hence, the proposed antenna could work under high-shock conditions. In comparison of monopole antennas at same frequency, helical antennas using normal mode have much smaller axial height which can be obtained by Eq. (1).

\[ L_S = \left( \frac{\pi \lambda}{10} \right) \times (L/D)^{0.2} \]  

(1)

where \( L \), \( D \) and \( L_S \) are axial height, diameter and length of the proposed helix antenna respectively. When the requirement \( D/\lambda \leq 0.18 \) is met, the helical antenna could work at the normal mode. Finally, \( D \) and \( L \) are set to 9 mm and 21 mm respectively.

A two-stage LNA module is implemented to realize more than 28 dB gain with flatness less than 0.5 dB and less than 0.9 dB noise figure (NF) at BDS B3 band utilizing commercial amplifier chips ATF54143 (Avago), MGA-86563 (Avago) and SAW filter TA0862A (TAI-SAW). It should be mentioned that the parameters like gain of the proposed module could be tuned by changing the resistor values of the Pi attenuator easily.

3. Results and discussions

The proposed antenna is designed and optimized using commercial full-wave electromagnetic simulator HFSS. The optimized geometrical parameters are listed in Table I. The prototype as shown in Fig. 2 is fabricated and measured.

| Parameters | Values |
|------------|--------|
| \( D_{pdb} \) | 9 mm |
| \( D_{az} \) | 4.6 mm |
| \( W_1 \) | 22 mm |
| \( W_2 \) | 3.6 mm |
| \( L_1 \) | 1.5 mm |
| \( L_2 \) | 3.5 mm |
| Alpha | 79° |
| Beta | 60° |
| Theta | 18° |

It can be seen from Fig. 1 that a grounded matching stub is introduced to improve impedance matching. The simulated impedances in presence and absence of the grounded matching stub are illustrated in Fig. 3 for comparison. It can be concluded that an optimized matching stub can transform the input impedance.
(usually a complex impedance) of the helical antenna to 50 Ω.

The simulated and measured reflection coefficients are shown in Fig. 4. Good agreement can be observed while the measured impedance bandwidth (|S_{11}| < 10 dB) is 15 MHz centered at 1268 MHz, a little wider than the simulated bandwidth. By lengthening or shortening of the copper strip, the working frequency of the presented antenna can be easily tuned.

Fig. 5 depicts the simulated radiation patterns in E and H planes respectively. The E-plane pattern is nearly '∞' shaped with peak gain around 2.0 dBi while an omnidirectional pattern is achieved in H-plane. To prove the capability of signal reception of the proposed antenna, an experiment is carried out. The proposed antenna is placed in a variety of gestures, meanwhile it is connected to a BDS receiver, recording the signal-to-noise ratio (SNRs) of the received signal. The recorded SNRs are shown in Fig. 6. It can be concluded that the proposed antenna can provide stable signal reception under various motion attitudes of the carrier while the SNRs of the received signal and the number of satellites involved in the positioning change slightly.

An anti-impact experiment is carried out using an air cannon during which the acceleration exceeds 20000 g.
The proposed antenna hasn’t damaged and receives signal normally after the experiment, proving that the proposed antenna can satisfy requirements for high-shock projectile applications.

4. Conclusion

A compact active antenna operating at BDS B3 (1268 MHz) band is presented for high-shock projectile applications based on the theory of normal mode helical antenna. A grounded matching stub is introduced for good impedance matching. The proposed antenna, of extremely compact size (22×22 mm), is fabricated and experimentally investigated. An omni-directional pattern in broadside of the antenna is achieved and the capability of stable signal reception under various motion attitudes is verified by experiments, which are in good agreement with simulations. The capability of working under high-shock environments is also experimentally verified. Because of its attractive merits of extremely compact size, omni-directional pattern and mechanically robust structure, the proposed antenna has great potential in the high-shock projectile applications where compact size and high shock are the major concerns.

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