Two-Element Conformal Antenna for Multi-GNSS Reception

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Abstract—This letter presents a two-element conformal antenna for receiving the global positioning system L1, L2, and GLONASS L1 signals for precision artillery applications. The antenna consists of two stub-loaded shorted conformal patches fed by coaxial cables and a stripline power combiner. The patch is realized on a cylindrical polymer substrate wrapped around an artillery fuze body. Two patches are placed 180° apart and combined to realize an omnidirectional pattern. The fabricated antenna shows good Global Navigation Satellite System signal receiving performance.

Index Terms—Conformal antenna, dual-band antenna, multi-GNSS reception, precision artillery.

I. INTRODUCTION

SATELLITE positioning techniques have been actively developed to improve the accuracy of conventional artillery projectiles. Some examples include the Excalibur, precision guidance kit (PGK), and mortar guidance kit [1]–[3]. The antenna receiving Global Navigation Satellite System (GNSS) signals is placed usually in the projectile fuze, where space constraints severely limit antenna choices. The simultaneous use of GNSS signals at different bands helps in reducing jamming vulnerability and in improving positioning accuracy. Existing literature works on multiband GNSS antennas for artillery applications are limited. The folded monopole in [4] and the edge slot antenna in [5] have a drawback in that they use almost the entire space inside the fuze radome.

Many antenna designs have been proposed for dual- or multiband operation such as a slotted circular patch [6]–[8], stacked patches [9], a stub-loaded patch [10]–[11], monopole [12]–[13], and novel structures for mobile phones [14], [15]. For size reduction, inverted-F, planar inverted-F, and shorted patch types are attractive. Dual-band operation with a shorted patch has been realized by using a stacked patch [16], a slot on the patch [17], and a stub [18].

In this letter, we present a new antenna for multi-GNSS reception [Global Positioning System (GPS) L1/L2 and GLONASS] that is mountable on an artillery fuze. A rugged and conformal antenna is obtained by using a probe-fed shorted patch loaded with a stub that is placed very close to the patch. The antenna element takes up a very small space of only $0.143 \times 0.092 \times 0.016$ wavelength. Two patches are realized on a thin plastic film that is firmly bonded to a cylindrical polymer substrate. Two patches are 180° apart from each other and fed by a stripline power combiner specially designed for easy installation in an artillery fuze. The following sections describe the design and measurement of the proposed antenna.

II. ANTENNA DESIGN

Fig. 1(a) shows the proposed antenna along with a fuze body that consists of a radome ($R$), the upper metallic fuze body ($U$), and a cylindrical substrate ($D$). The portion denoted $L$ is the upper part of a projectile body. The fuze is to be installed on top of a projectile such as the 120- and 155-mm artillery shells. The patch ($P_2$) is shorted to the upper fuze body ($U$) in one of its top

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Fig. 2. Design parameters of the patch. (a) Planarized view. (b) Cross section.

edges and stub-loaded in one of the nonradiating side edges for dual-band operation.

Fig. 1(b) shows the cross section of Fig. 1(a) at the patch’s feed point showing the cylindrical substrate (D) of thickness t, the fuze’s metallic body (F), a feed network circuit board (S), and coaxial cables (C0, C1, and C2) and two patches (P1 and P2). The nylon 66 material is chosen for the cylindrical substrate having dielectric constant of 3.0 and tangent loss of 0.02. Its outer diameter is 60 mm, thickness 4 mm, and height 34 mm. The projectiles’ upper body (L) and the fuze body (F) are joined by screw threads integrated in the respective bodies. The cylindrical part is an addition to the fuze body that slightly modifies the aerodynamics of an artillery projectile. The addition of the cylindrical space is inevitable since no space is available for antenna installation inside the fuze of an existing form factor and the projectile’s ogive shape remains unchanged. The PGK also uses an additional cylindrical space for antenna installation [2].

Two patches (P1 and P2) are placed on the cylindrical substrate 180° apart and combined by the feed network with equal amplitudes and phases for an omnidirectional pattern around the fuze axis. The patches are connected to the feed network by coaxial cables (C1 and C2) at two input port pads (J1 and J2). The feed network output port pad (Q) is connected to a GNSS receiver inside the fuze body by a coaxial cable (C0). The RG-405 semiflexible cable is used for C0, C1, and C2.

Fig. 2(a) is a planarized view of the antenna surface showing the design parameters of the patch, and Fig. 2(b) is a cross-sectional view corresponding to Fig. 2(a). The upper edge of the patch is shorted to the fuze body for size reduction. The patch is fed at a point near its shorted edge by a coaxial probe. An open stub is connected to one of the patch’s side edges for operation at the L2 frequency. The open stub is placed close to the patch for size reduction and for proximity coupling with the patch enabling another resonance at the GPS L2 frequency. The stub length (S1 + L4 + L5) determines the resonance at the GPS L2 frequency. The gap s2 between the open stub and the patch is critical to forming a resonance at the GPS L2 frequency. Too large a value of s2 does not provide an L2 resonance at all.

When the stub is added, the patch’s initial resonance frequency changes, which is compensated by iteratively adjusting S1, S2, L1, and L3. Impedance matching at two bands is obtained by properly adjusting the feeding probe position (g) and the stub position (L3). Based upon the concept outlined above, an optimum design of the antenna is obtained by manual iterations and parameter sweeps using CST Microwave Studio.

Final dimensions of the designed patch are as follows: t = 4 mm, L0 = 34 mm, L1 = 30.8 mm, L2 = 20.7 mm, L3 = 9.9 mm, L4 = 21.9 mm, L5 = 21.2 mm, S1 = 1.0 mm, S2 = 0.3 mm, W = 0.7 mm, and g = 5 mm.

Fig. 3(a) shows the stripline feed network circuit pattern. It consists of two input port pads (I1 and I2), an output port pad (O), two 70.7-Ω quarter-wave lines (L1 and L2) for transforming 50-Ω patch impedance into 100 Ω, via holes (V) for suppressing parallel-plate mode in the stripline, screw holes (H) for circuit board installation, and openings (W) for input/output cable routing. The stripline is laid out so that it does not overlap the feed network [not shown in Fig. 3(a)] for a telemetry antenna. Fig. 3(b) shows a transition between the coaxial cable and the stripline. The inner conductor C1 in of the coaxial cable is connected to the stripline by the via hole V1 and pads I1, I1, and K1, while the outer conductor C1 out is soldered to the ground plane G. The diameter of the pads J1, I1, and K1 and the gap M between pads J1, I1 and the ground plane G are optimized for low discontinuity parasitics and for low radiation.

III. ANTENNA FABRICATION AND MEASUREMENT

Fig. 4 shows the fabricated antenna. The patches are etched on a copper-clad Kapton film and firmly bonded onto the cylindrical substrate using JB Weld’s PlasticWeld. The antenna surface is protected with a thin layer of acrylic lacquer spray. A separate radome layer is not applied considering the fact that the fuze is
Fig. 4. Fabricated antenna. (a) Overall structure. (b) Feed network circuit board.

Fig. 5. Reflection coefficient of the fabricated antenna.

Fig. 6. Gain patterns in the elevation plane (solid line: simulation, dashed line: measurement). (a) At GPS L2 band \((f = 1.227 \text{ GHz})\). (b) At GPS L1 band \((f = 1.575 \text{ GHz})\).

Fig. 7. Gain patterns in the azimuth plane (solid line: simulation, dashed line: measurement). (a) At GPS L2 band \((f = 1.227 \text{ GHz})\). (b) At GPS L1 band \((f = 1.575 \text{ GHz})\).

The feed network is realized using two layers of 0.5-mm-thick reinforced PTFE substrate with dielectric constant 2.5 and loss tangent 0.002. The performance of the feed network alone is measured and verified before connecting with the antenna.

Fig. 5 shows the measured reflection coefficient of the fabricated antenna that is below –6 dB over 1.213–1.239 and 1.558–1.622 GHz and agrees well with the simulation. Figs. 6 and 7 show the measured gain patterns in the elevation and azimuth planes. The fabricated antenna has maximum gains of 0 and 0.5 dBi at GPS L2 and GPS L1 bands, respectively. The horizontal gains are –0.7 and –1.2 dBi at respective frequencies. The gain patterns at GLONASS L1 band are similar to those at GPS L1 band. The gain variation in the horizontal plane is due to the fact that only two elements are used. Use of three or four elements should reduce the gain variation.

Fig. 8 shows measured \(C/N_0\) ratios of the GNSS signals received by the fabricated antenna with the fuze axis elevated by 45° from the ground. A commercial receiver Propak 6 by Novatel is used. The experiment has been carried out on a rooftop with nearby buildings blocking part of the sky. The antenna is placed on a plastic foam support 2 m above the rooftop surface. The GNSS reception performance has been found not sensitive to

stored and carried in a protective package and is taken out of the package and installed on the projectile body just before firing.
the fuze elevation angle. A slightly better performance has been observed with the fuze axis parallel to the rooftop surface.

The number of GNSS satellites acquired at GPS L1, L2, and GLONASS L1 bands are 8, 8, and 6, respectively, while the $C/N_0$ ratios in decibels–hertz (dB–Hz) are 35–39 (average 36), 30–37 (average 33), and 35–40.5 (average 37) at respective bands, which are satisfactory since present GNSS receivers require a set of four GNSS signals with $C/N_0$ ratio greater than 35 dB–Hz for position fix even on highly dynamic platforms with the aid of assistance information such as the A-GPS. The reduced performance at the L2 frequency is due to the fact that the antenna has a smaller gain and more oblong horizontal gain pattern at the L1 frequency.

VI. CONCLUSION

In this letter, a new multiband GNSS antenna receiving at GPS L1/L2 and GLONASS L1 signals has been proposed for precision artillery applications. The proposed antenna consists of two conformal shorted patches that are realized on a cylindrical substrate around a fuze body and fed by a stripline feed network. Critical to the operation at the GPS L2 frequency is an open bent stub connected to the side edge of the patch. The bent portion of the stub is placed in close proximity to the patch’s lower edge to ensure a resonance at the L2 frequency.

Measurements of the fabricated antenna showed that the proposed antenna has –6-dB reflection coefficient bandwidths of 64 MHz at the GPS L1/GLONASS L1 bands and 26 MHz at the GPS L2 band. The $C/N_0$ ratios of the GNSS signals received by fabricated antenna are suitable for reliable position fix. The proposed antenna concept can be employed for receiving multiband GNSS signals on board an artillery fuze using a small antenna installation space.

REFERENCES