Compact Circularly Polarized Antenna with a Capacitive Feed for GPS/GLONASS Applications

Seong Jae Jeong, Keum Cheol Hwang, and Do-In Hwang

This letter presents a novel compact circularly polarized patch antenna for Global Positioning System/Global Navigation Satellite System (GPS/GLONASS) applications. The proposed antenna is composed of a simple square radiating patch fed by a capacitive dual-feeder to increase the impedance bandwidth and a lumped element hybrid coupler to achieve the broadband characteristic of the axial ratio (AR). The realized antenna dimensions are 28 mm × 28 mm × 4 mm, which is the most compact size among the dual-band GPS/GLONASS antennas reported to date. The measured results demonstrate that the proposed antenna has a gain of 2.5 dBi to 4.2 dBi and an AR of 0.41 dB to 1.51 dB over the GPS/GLONASS L1 band (1.575 GHz to 1.61 GHz).

Keywords: Slot antenna, circular polarization, Global Positioning System, GLONASS, capacitive feed.

I. Introduction

Recently, many countries, such as the United States, Russia, China, and several European countries, have developed a global navigation satellite system (GNSS) as a means of navigating, surveying, and mapping [1]. For GNSS applications, the demand for circularly polarized antennas is increasing steadily, as they can cover a large service area and provide a stable signal quality. Various patch antennas have been proposed to implement circular polarization [2]-[7]. In [2]-[4], the circular polarization of a microstrip patch antenna was achieved by embedding a cross-slot of unequal arm lengths, inserting spur lines at the patch boundary, and applying an asymmetric-slit patch. Traditional microstrip patch antennas show a limited impedance bandwidth and a "V"-shaped axial ratio (AR) curve, which implies a narrow AR bandwidth. To enhance the impedance bandwidth, several techniques have been suggested, such as proximity coupling and the use of an aperture-coupled structure [5], [6]. Although the proximity coupling and aperture-coupled techniques are useful for improving the impedance bandwidth, such a stacked configuration can increase the manufacturing cost significantly. Another candidate to enhance the AR bandwidth involves the use of two or more pairs of out-of-phase sources, which are provided by balanced feeds, such as branch-line couplers and a Wilkinson power divider [7]. However, the geometries of these couplers are not suitable for monolithic integration with radio frequency (RF) active devices, due to their large dimensions.

In this letter, a miniaturized broadband circularly polarized patch antenna with a capacitive dual-feed for Global Positioning System/Global Navigation Satellite System (GPS/GLONASS) applications is presented. By using the capacitive feeding method, the proposed antenna effectively cancels out the inductance component caused by the feeding probe, thus resulting in broadband impedance matching [8]. The broadband AR characteristic is also realized by utilizing a compact hybrid coupler with an equal amplitude and a 90° phase difference based on an *L-C* lumped element. Because the lumped element hybrid coupler is much more compact in size than conventional couplers [9], such RF modules as a low-noise amplifier (LNA) and filter can be easily integrated into the extra area of a single-layer RF substrate. Details of simulation and measurement results pertaining to the proposed antenna are presented and discussed in the following sections.

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II. Antenna Design

The geometry of the proposed circularly polarized patch antenna with a capacitive dual-feed is shown in Fig. 1. A square radiating patch and capacitive feeding patches are etched onto the upper side of the ceramic substrate with a high dielectric constant of ε_r=20.

The ceramic substrate measures 28 mm × 28 mm × 4 mm, which are suitable dimensions for compact GNSS receivers. Consistent with an earlier study [8], the square radiating patch is designed to operate at the central frequency of the GPS/GLONASS L1 band (1.575 GHz to 1.61 GHz). Although the designed patch has a very compact size of 19.15 mm × 19.15 mm due to the high dielectric constant of the ceramic substrate, the use of a high-permittivity substrate also decreases the impedance bandwidth [10]. Therefore, instead of direct probe feeding, we employ a capacitive feeding method to enhance the bandwidth characteristics. The function of a capacitive feeding patch is to introduce a capacitance component that can suppress the inductance induced by the vertical feeding probe, thereby enhancing the impedance bandwidth.

The capacitive feeding patches with dimensions of 4 mm × 7 mm are placed 10 mm away from the center of the square radiating patch at φ=45° and φ=135°. The gap between the radiating patch and the capacitive feeding patch is 0.425 mm.

The ground plane, having a size of 30 mm × 30 mm, is located on the upper side of the 0.8-mm FR-4 substrate with a dielectric constant of 4.6 and a loss tangent of 0.02. The feeding probes soldered to the capacitive feeding patch are connected to the output ports of the lumped element hybrid coupler, which is placed on the bottom side of the FR-4 substrate. The lumped element hybrid coupler serves to excite two orthogonal, linearly polarized modes with an equal amplitude and a 90° phase difference, resulting in right-handed circular polarization (RHCP) or left-handed circular polarization (LHCP).

The topology of the lumped element hybrid coupler is shown in Fig. 2. The overall structure of the proposed hybrid coupler is symmetric; thus, the even-odd decomposition method can be applied for the analysis. A detailed description of the theoretical aspects of the quadrature hybrid design is available in the literature [9]. The following results of (1) to (4) are obtained by analyzing the even mode and odd mode half circuit:

$$S_{11} = \frac{1}{2}(S_{11}^e + S_{11}^0) = 0, \tag{1}$$

$$S_{41} = \frac{1}{2}(S_{21}^e + S_{21}^0) = 0, \tag{2}$$

$$S_{21} = \frac{1}{2}(S_{11}^e - S_{11}^0) = \frac{1}{2}(1 - j), \tag{3}$$

$$S_{31} = \frac{1}{2}(S_{21}^e - S_{21}^0) = \frac{1}{2}(1 + j). \tag{4}$$

We observe three issues about the hybrid coupler from the above expressions. First, the hybrid is matched and has perfect isolation because S_{11}=0 and S_{41}=0. Second, the power exiting port 1 is delivered identically to ports 2 and 3. Finally, the phase difference between the signals at through-port 2 and coupled-port 3 is exactly 90°. Therefore, the results of (1) through (4) demonstrate that the hybrid coupler delivers an equal amplitude and a 90° phase difference.

Based on the above expressions, a lumped element hybrid coupler operating at 1.594 GHz is designed. The values of the passive lumped elements L and C are 4.7 nH and 1.8 pF,

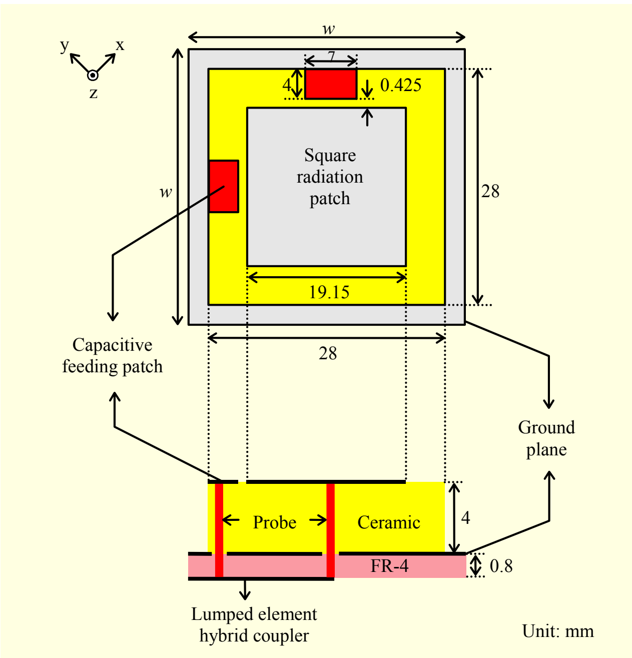

Fig. 1. Geometry of broadband circularly polarized patch antenna with capacitive dual-feed.

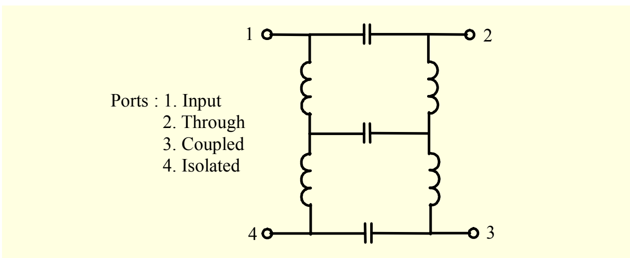

Fig. 2. Lumped element hybrid coupler circuit.

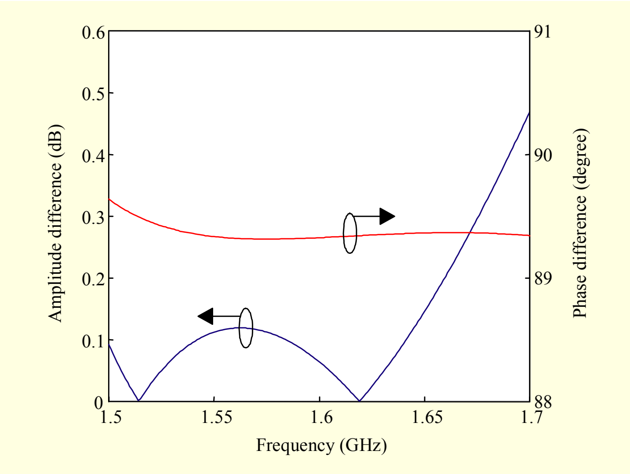

Fig. 3. Simulated amplitude and phase differences between output ports.

respectively. The simulated amplitude and phase responses of the hybrid are illustrated in Fig. 3. We observe that the hybrid coupler delivers a balanced power distribution ($|S_{21}|-|S_{31}|<0.5$ dB) and a consistent 90° phase difference ($\angle S_{21}-\angle S_{31} < 1°$) from 1.5 GHz to 1.7 GHz.

III. Measured Results

The proposed antenna shown in Fig. 1 is fabricated and tested to verify the antenna performance. The physical layout of the fabricated structure is shown in Fig. 4, in which both top and bottom views are shown. As shown in Fig. 4(b), other RF modules can be embedded onto the identical layer of the FR-4 substrate with a feeder and coupler, due to the compact dimension of the lumped element hybrid coupler. We employ a 4.7 nH chip inductor and a 1.8 pF chip capacitor from the Murata corporation for the implementation of the hybrid coupler. Port 1 (the input port) is connected to a semi-rigid coaxial cable for the purpose of measurement, while port 4 is terminated by a 50-Ω load to absorb the reflected wave.

Figure 5 shows the measured reflection coefficient of the fabricated antenna with simulation results achieved using the ANSYS HFSS tool based on the finite element method [11]. Although the impedance bandwidth decreases as the dimension of the ground plane increases, the proposed antenna exhibits a sufficiently wide impedance bandwidth to cover the GPS/GLONASS L1 band. The input reflection coefficient is measured by an Agilent 8510C vector network analyzer. It is found to be less than –18 dB from 1.575 GHz to 1.61 GHz. Discrepancies in the values of the measured and simulated reflection coefficient are mainly the result of not taking the effect of a coaxial cable into account in the simulation.

Measurements of the AR and realized gain are also performed in an RF anechoic chamber. Figure 6 depicts the simulated and measured results for the AR and gain of the fabricated antenna. We observe that the measured level of AR

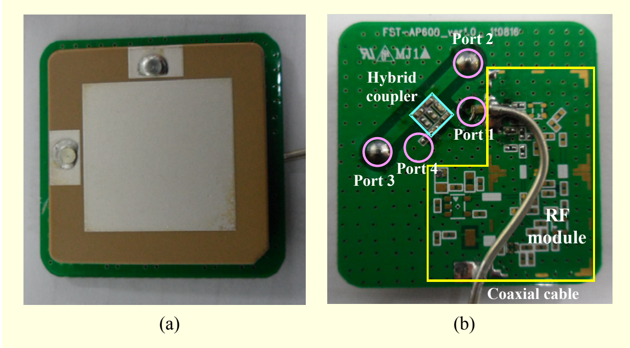

Fig. 4. Photograph of broadband circularly polarized patch antenna with capacitive dual-feeder: (a) top view and (b) bottom view.

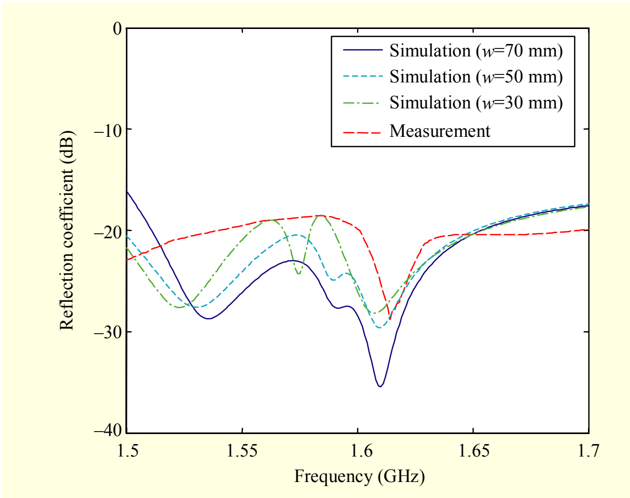

Fig. 5. Measured and simulated reflection coefficient.

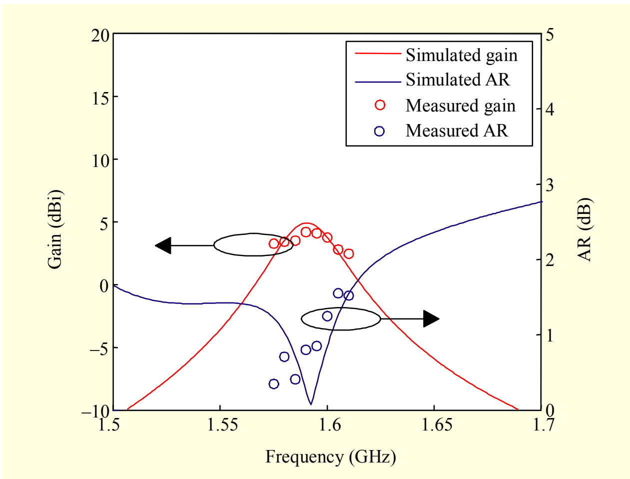

Fig. 6. Measured and simulated axial ratio and gain.

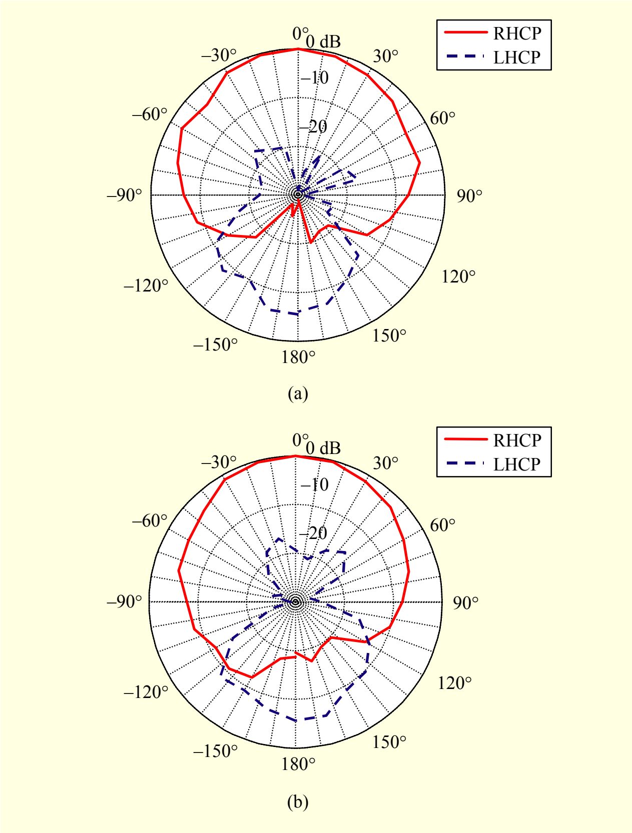

Fig. 7. Measured radiation patterns at 1.594 GHz (a) x-z plane and (b) y-z plane.

ranges from 0.41 dB to 1.52 dB at all measured frequencies.

The measured angular coverage with an AR value of less than 3 dB is shown to be 153° ($-79° < \theta < 74°$) on the x-z plane and 211° ($-113° < \theta < 98°$) on the y-z plane at 1.594 GHz. Figure 6 also shows the measured and simulated gain of the fabricated antenna. Agreement is obtained between the simulated and measured results. The measured gain of the antenna is 2.5 dBi to 4.2 dBi over the GPS/GLONASS L1 band. The radiation patterns of the fabricated antenna are measured using a dual-polarized horn antenna for the two principal planes of φ=0° (x-z plane) and φ=90° (y-*z* plane). The normalized radiation patterns at 1.594 GHz in both the x-z and y-z planes are plotted in Fig. 7. We find that the level of RHCP (co-polarization) is more than 20 dB higher than that of the LHCP (cross-polarization) in the +z-direction at the measured frequency. A high front-to-back ratio over 20 dB is also obtained.

IV. Conclusion

In this letter, a compact circularly polarized patch antenna with a capacitive dual-feed for GPS/GLONASS applications was developed. An enhancement of the bandwidth of the proposed antenna was achieved by introducing a capacitive feeding method that cancels out the inductance induced by the vertical feeding probe. A lumped element hybrid coupler with an equal amplitude and a 90° phase difference was also applied to realize the broadband performance of the AR. The measured results demonstrated that the proposed circularly polarized patch antenna exhibits a high gain that exceeds 2.5 dBi and a low AR level of less than 1.52 dB in the GPS/GLONASS L1 band. Therefore, the antenna proposed in this letter is feasible for use in a GPS/GLONASS receiver.

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