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Design of Microstrip Antenna for Satellite Navigation System Jamming

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ABSTRACT

This paper proposed a microstrip antenna that can perform jamming of satellite signals from the GPS L5, GLONASS G3, BDS B2 frequency bands (1164 – 1217 MHz) that are employed mainly for military purposes among the GNSS frequencies using unmanned aircrafts over the enemy's sky in time of emergency. The single element in the proposed antenna can be easily mounted to unmanned aircrafts. This study analyzed the characteristics of miniaturization and beam of radiating elements by applying the image theories and perturbation effect to satisfy the uniform level at ±45° of beam steering goal due to the phase delay after antenna array. The designed microstrip antenna had a miniaturized radiating element area (x-y plane), which was reduced by 76.3% compared to that of basic microstrip antenna, and its beam width was 190° in the E-plane and 140° in the H plane. In addition, the simulation was conducted to determine the characteristics due to the phase delay by arranging the designed single microstrip antenna by 1×4 array and the results showed that beam steering of ±45° is possible in the H-plane on the basis of 0°. Thus, the proposed antenna was verified to be effective in satellite signal jamming in the air as it was attached to the lower end of unmanned aircrafts.

Keywords: jamming antenna, antenna miniaturization, beam steering

1. INTRODUCTION

A Global Navigation Satellite System (GNSS) refers to a system that provides real-time position, moving object speeds, and accurate time information using satellites. It has been used in command and control systems as well as precise attack military systems including guided weapons and Unmanned Aerial Vehicle (UAV), which are considered as the core military power in modern wars (Ko 2010). Developed nations have operated their own satellite navigation systems such as the Global Positioning System (GPS) in the USA and Global Navigation Satellite System (GLONASS) in Russia to manage their state-of-the-art military systems efficiently. China has also started servicing with their own satellite navigation system Beidou Navigation Satellite System (BDS) and applied the BDS to military strategic communications. However, since satellites in the satellite navigation systems transmit signals from far locations (approximately 20,000 km) from the Earth, their reception signal sensitivity is very weak and signals are highly vulnerable to interference (Kaplan & Hegarty 2005). Studies have been actively conducted on jamming technology to interrupt signal reception in recent years using the vulnerabilities of signals by applying strong power frequency signals of the same frequency in the frequency band used by satellite navigation signals. In addition, the effect of jamming signals of 1 W to 10 W, which affected satellite navigation system receivers around a radius of several dozen km, has been practically proven through cases including Iraq War in 2003 (Kim 2013).

Generally, antennas used for jamming have two types: monopole and reflector antennas. A monopole antenna for jammer application is highly portable but not suitable to use high-power sources. As for a reflector antenna, it has been adopted to high power microwave, and a study has been conducted (Rahmat-Samii et al. 1992). However, an antenna for jamming used in this paper was mounted

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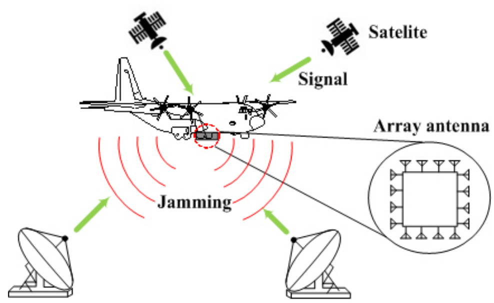

Fig. 1. Example of the jamming antenna attached to the bottom of an UAV.

on the lower end of UAV. Thus, the size of the reflector antenna was not physically suitable to be mounted on the UAV. Thus, it is desirable to use microstrip antennas as antennas for jamming that are mounted on the lower end of UAVs as they have advantages of high efficiency power control, beam steering characteristics as well as superior array characteristics. In this regard, this paper designed a microstrip antenna that can perform jamming of signals in the frequency band (1164 – 1217 MHz) of GPS L5, GLONASS G3, and BDS B2 mainly used for military purposes among the GNSS frequency bands in the air. This paper aims to perform efficient jamming against guided weapon systems or military command control systems in time of emergency over the enemy's sky, and as for beam steering in the array antennas attached to UAV, the goal is to maintain the level within a range of ±45°.

This paper is organized with two chapters. Chapter 2 analyzes the characteristics of basic microstrip antennas to present a miniaturization technology by applying image theories and perturbation effect to facilitate an array of microstrip antennas. It also describes a structural change process to have a 100° or larger half power beam width (HPBW) of single antenna to maintain a uniform level within a range of ±45°, which was a beam steering goal during the array of the single microstrip antennas. Chapter 3 analyzes the beam steering characteristics according to the phase change by arranging the designed single microstrip antennas by 1×4 array, and the design procedure and results are described.

2. DESIGN OF SINGLE MICROSTRIP ANTENNA

2.1 Reference λ/2 Microstrip Antenna

Fig. 2 shows the simulation structure of the $\lambda/2$ microstrip antenna that is the basis of this study. A size of the radiating element at the center frequency of 1191 MHz was 112 mm (0.44λ) × 110 mm (0.437λ) × 10 mm (0.04λ) and a size of the ground was 252 mm (1.0λ) × 252 mm (1.0λ).

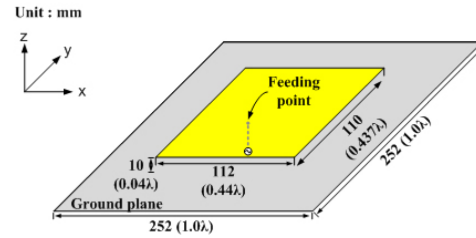

Fig. 2. Structure of the reference λ/2 microstrip antenna.

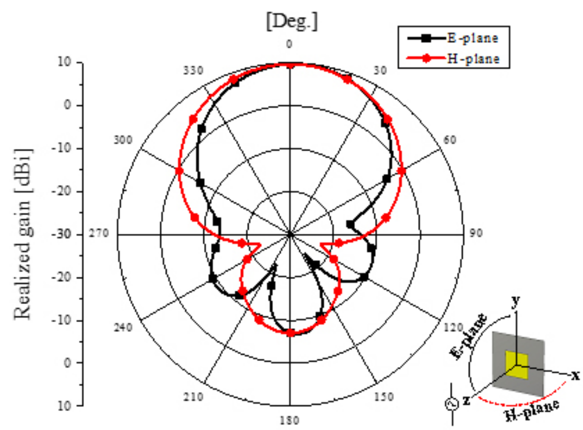

Fig. 3. Radiation pattern of the reference λ/2 microstrip antenna.

Fig. 3 shows the radiating pattern of the $\lambda/2$ microstrip antenna, in which 9.76 dBi was obtained as a gain at the center frequency, 1191 MHz, and HPBW was 53.6° at the E-plane and 63.8° in the H-plane. However, since an area (x-y plane) of the radiating element is too large to attach and arrange the antennas at the lower end of UAV, which is the goal of this paper, miniaturization is needed and HPBW of the single antenna should satisfy 100° or larger to maintain a uniform level of beam steering angle within a range of ±45° when beam steering is done by arraying the antennas. Thus, a structural change in the antenna is needed to miniaturize the antenna structure and ensure 100° or larger HPBW.

2.2 Miniaturization of the Antenna Applying Image Theory

Fig. 4 shows the simulation structure of the microstrip antenna to which image theory (Pozar 2012) is applied. The radiating element antenna is vertically structured on the ground surface in the antenna and a size of the radiating element in the antenna is 24 mm (0.095λ) × 85 mm (0.337λ) × 58 mm (0.23λ). Compared to a size of the radiating element in the $\lambda/2$ microstrip antenna, a size of the antenna

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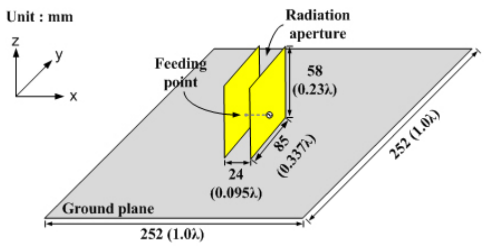

Fig. 4. Structure of the microstrip antenna applying the image theory.

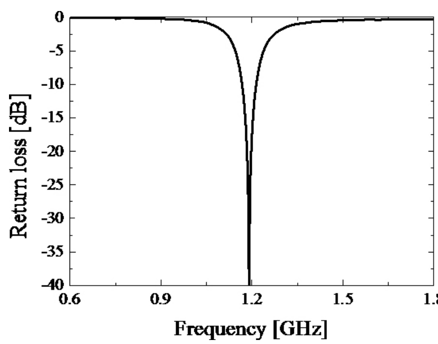

Fig. 5. Return loss of the microstrip antenna applying the image theory.

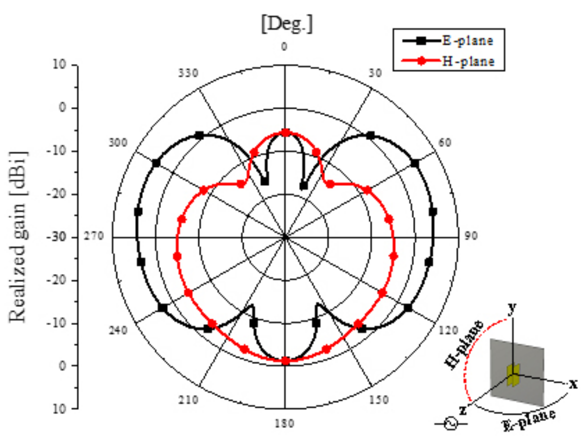

Fig. 6. Radiation pattern of the microstrip antenna applying the image theory.

was miniaturized by 83.4% but a height was increased by 48 mm, which required additional miniaturization to reduce a height.

Fig. 5 shows the return loss of the microstrip antenna to which image theory is applied. By adjusting a gap between the radiating elements created vertically on the ground surface though applying the image theory, it was matched to the center frequency of 1991 MHz when a gap was 24 mm, and a return loss was -40.1 dB. The -10 dB bandwidth was 53 MHz, which satisfied the goal frequency band (1164 – 1217 MHz).

Fig. 6 shows the radiating pattern of the microstrip antenna to which image theory is applied. The maximum gain was 4.85 dBi at the E-plane 84°. The radiating patterns

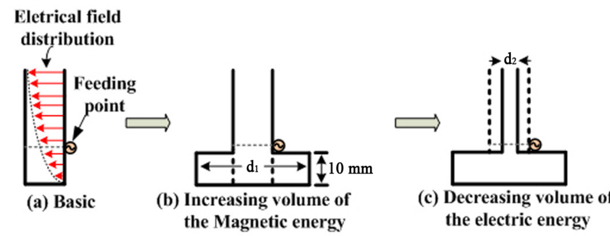

Fig. 7. Principle of the miniaturization of the antenna using cavity volume change.

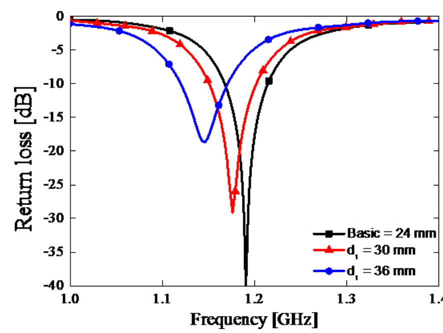

Fig. 8. Resonant frequency characteristics due to the expansion of intervals of strong magnetic field energy.

in the E-plane and H-plane showed that a gain was decreased at 0° of the radiating opening surface and the goal of HPBW set in this paper was not satisfied. Thus, it is necessary to improve the beam pattern by modifying the structure of the antenna.

2.3 Miniaturization Using the Cavity Volume Change

Fig. 7 shows the conceptual diagram that explains the antenna miniaturization principle using changes in cavity volumes of the microstrip antenna structure to which image theory is applied as designed in Section 2.2. To apply the perturbation effect, the inside of the microstrip antenna was divided into two parts: where electric field energy was strong and magnetic field energy was strong. Then, cavity volume was changed (Song & Woo 2003, Moon et al. 2011).

Fig. 8 shows the characteristics of changes in resonance frequency as a volume where the magnetic field energy in Fig. 7b was strong was increased (expansion of the gap). The result showed that when a height of the antenna was fixed to 10 mm and d1 was increased from 24 mm to 36 mm by 6 mm gap increment, the resonance frequency was decreased from 1191 MHz to 1146 MHz.

Fig. 9 shows the characteristics of changes in resonance frequency as a volume where the electric field energy in Fig. 7c was strong was decreased (reduction in the gap). The characteristics of changes in resonance frequency were

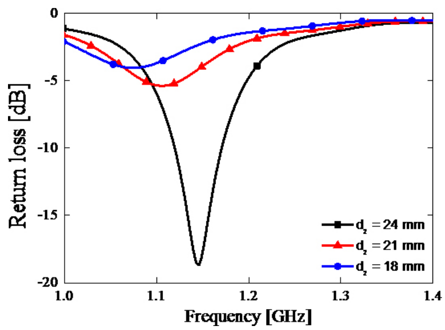

Fig. 9. Resonant frequency characteristics due to the reduction of intervals of strong electric field energy.

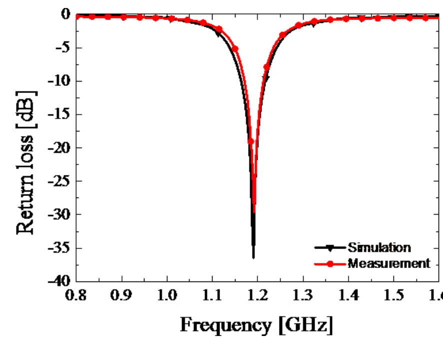

Fig. 11. Return loss of the proposed single microstrip antenna.

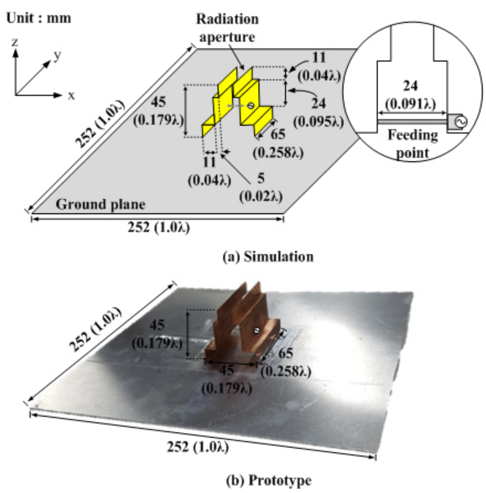

Fig. 10. Structure of the proposed single microstrip antenna.

verified when d_1 was fixed to 36 mm and then a gap of d_2 was reduced from 24 mm to 18 mm, the resonance frequency was decreased from 1146 MHz to 1074 MHz. This was because the leakage field effect became weaker as the gap of opening in the antenna became narrower. By applying the perturbation effect, it was verified that the decrease in resonance frequency according to changes in volume at which electric field energy was strong and at which magnetic field energy was strong inside the microstrip antenna can ultimately miniaturize an antenna size at the design frequency.

2.4 Single Microstrip Antenna

Fig. 10 shows the final simulation structure and prototype structure of the single microstrip antenna. The antenna was configured with multi-layers by applying the perturbation effect as described in Section 2.3 and its size was modified to d_1 = 45 mm and d_2 = 13 mm. A size of the radiating element in the antenna was designed and fabricated to have 45 mm (0.179λ) × 65 mm (0.258λ) × 45 mm (0.179λ).

Fig. 11 shows the return loss of the microstrip antenna proposed in this study. By changing the feed point position of the structurally modified antenna, it was matched to the center frequency of 1991 MHz. S11 represented simulation of -36.5 dB and measurement of -28.9 dB, and the -10 dB bandwidth was 53 MHz, satisfying the goal frequency band (1164 – 1217 MHz).

Fig. 12 shows the simulated and measured radiating patterns of the single microstrip antenna. The radiating pattern at the center frequency of 1991 MHz showed a symmetrical pattern centered around 0° and a gain obtained was simulation of 2.4 dBi and measurement of 2.5 dBi. As for the HPBW, simulation of 235° and measurement of 190° were obtained at the E-plane, and simulation of 106° and measurement of 140° were obtained in the H-plane, both satisfying the goal of 100° or higher HPBW. Even at the range of goal frequency band, which was 1164 – 1217 MHz, the HPBW was satisfied.

3. CHARATERISTICS OF THE ARRAYED JAMMING ANTENNA

In this chapter, the antenna was arranged by 1×4 array to verify the simulation characteristics in order to determine the beam steering characteristics according to the phase change of the designed single microstrip antenna.

Fig. 13 shows that the single microstrip antenna is arranged by 1×4 array using the EM Simulation tool and an array gap in the antenna is 150 mm (0.597λ). In addition, the phase of the arranged antenna was set to Port 2 = Φ°, Port 3 = 2Φ°, and Port 4 = 3Φ°.

Fig. 14 verifies the radiating pattern in the H-plane while changing phase Φ1 of 1×4 array antenna. At Φ = 0°, it showed that the maximum gain of the center frequency of 1991 MHz was 7.69 dBi and the beam width was 23°. At Φ

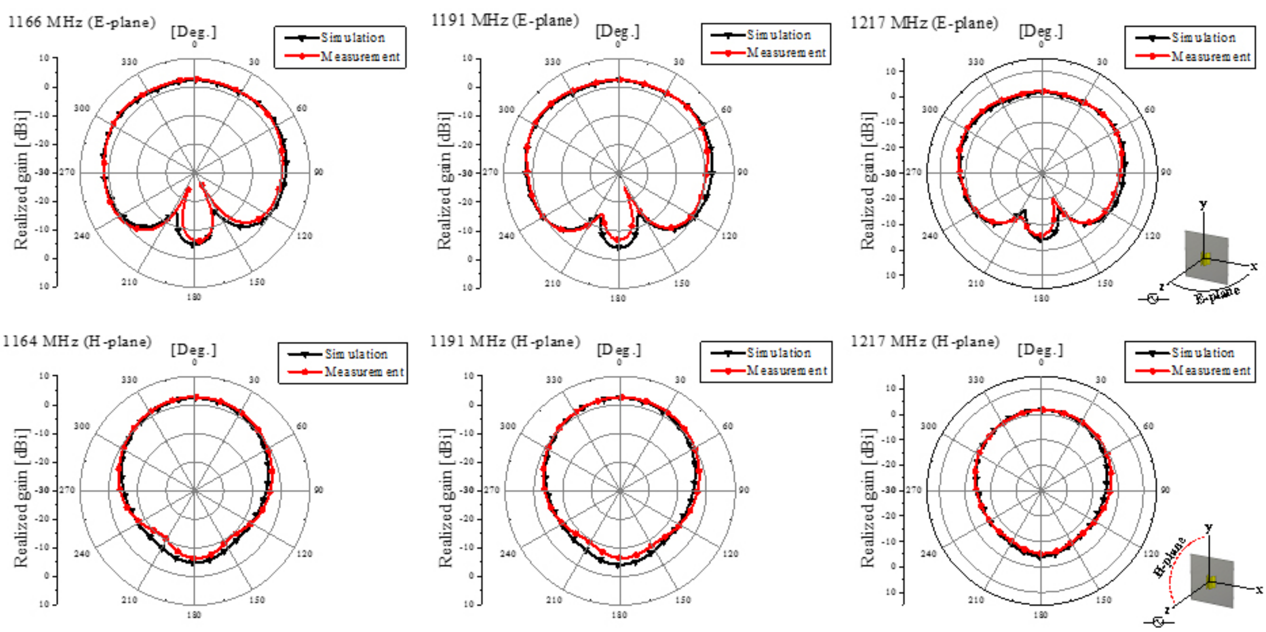

Fig. 12. Radiation patterns of the proposed single microstrip antenna.

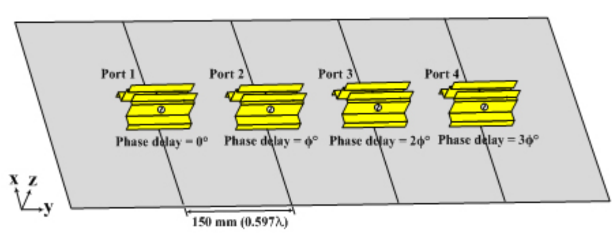

Fig. 13. Structure of the 1 x 4 array antenna.

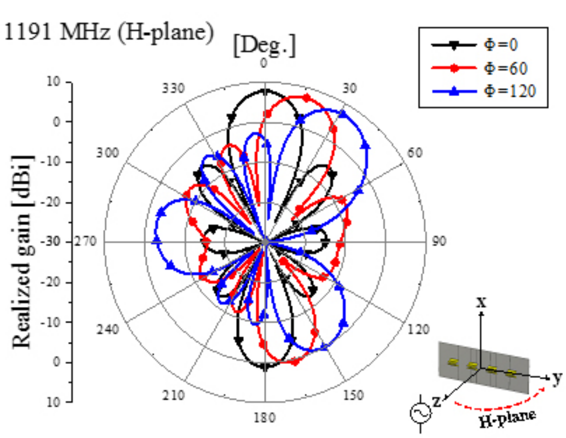

Fig. 14. H-plane radiation pattern due to the phasor change.

= 60°, the maximum gain was 7.52 dBi at 15° and the beam width was 23.8°. At Φ = 120°, the maximum gain was 7.4 dBi at 32° and the beam width was 27°. Thus, the above results verified that beam steering of ±45° on the basis of 0° can be achieved through the phase delay of the array antenna.

4. CONCLUSIONS

This study designed a microstrip antenna that can jam satellite signals at the frequency bands (1164 – 1217 MHz) of GPS L5, GLONASS G3, and BDS B2, which were mainly used for military purposes among the GNSS frequencies that were transferred to ground receivers using antennas for jamming attached to the lower end of UAVs.

The antenna was designed by applying the image theory and perturbation effect in order to miniaturize the radiating element of the single microstrip antenna. An area of the radiating element in the $\lambda/2$ microstrip antenna was 112 mm (0.44λ) × 110 mm (0.437λ), which was miniaturized to 45 mm (0.179λ) × 65 mm (0.258λ) of radiating element area in the single antenna designed in this study. The HPBW of the single antenna should be 100° or higher to maintain a uniform level at ±45° of beam steering according to the phase delay after antenna array, and the radiating pattern results of the fabricated antenna showed that the HPBW was 190° in the E-plane and 140° in the H-plane, satisfying the criterion of the single element in antennas for jamming.

In addition, the simulation was conducted to determine the characteristics due to the phase delay by arranging the designed single antenna by 1×4 array. The results showed that beam steering of ±45° was possible in the H-plane on the basis of 0°. Thus, it was confirmed that the proposed antenna was effective for satellite signal jamming in the air through the array of miniaturized single elements.

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