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A CIRCULARLY POLARIZED QUASI-LOOP ANTENNA

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Abstract—This paper presents a circularly polarized (CP) GPS/DCS loop-like antenna with a microstrip feed. The proposed antenna comprised of a quasi-C antenna, an inverted-L sleeve strip connected with the ground plane and an L-shaped slit embedded in the ground plane. The C-like antenna generates a resonant mode with a poor impedance matching condition. The inverted-L grounded strip and the embedded L-slit are not only capable of modifying two orthogonal electric fields with equal amplitude and phase difference of 90 degree for radiating circular polarization at 1.575 GHz, but the impedance characteristics is also improved and the operating frequency is reduced. Both simulated and measured results are provided to validate the impedance and CP performance of the proposed antenna. For the optimized antenna case, the measured bandwidth with an axial ratio (AR) of less than 3 dB is larger than 19% and the measured impedance bandwidth of reflection coefficient $S_{11} < -10$ dB is about 30.1%.

1. INTRODUCTION

Satellite communications have been extensively used for the data transmission, such as the voice or image. Recently, the global positioning system (GPS) has found increasingly many commercial applications since [1, 2] the 1980's release of the coded information transmitted by the US Department of Defense satellites. As known that the Faraday rotation effect [3] causes the linear-field vectors to rotate as a consequence of interaction with static magnetic fields along the propagation path. To reduce the polarization mismatch, antennas with circular polarization (CP) can be used for the GPS applications and the GPS antennas cover the frequency band of 1575 ± 2 MHz.

Due to low profile, low cost, light weight, wide bandwidth and easy integration with other devices, the planar monopole antenna is widely used for the wireless communication systems, such as GSM, DCS, CDMA, WLAN and UWB systems [4–12]. As well known, the microstrip monopole antenna can only radiate the linearly polarized (LP) wave with wideband bandwidth. Until to now, few studies of the circularly-polarized monopole antenna have been investigated. The design of the slitted ground has been proposed for the band-notch function of the UWB monopole antenna [13]. By simply embedding a small rectangular slit in the ground plane, a notched band can be achieved. In the past, we have proposed a microstrip monopole antenna with circular polarization and linear polarization by combining the monopole antenna and the inverted-L strip [14]. The CP radiation wave at 1.575 GHz is excited by the loop mode and the LP radiation wave at 1.8 GHz is excited by the monopole mode. However, the CP performance is not easy to achieve by tuning the geometrical parameters of the antenna.

In this paper, we present a microstrip-fed circularly-polarized loop-like antenna which meets the requirements of both a digital communication system and a global positioning system. Based on the studies in [14], by utilizing the coupling effect between the monopole antenna and sleeve, the excited resonant mode can be changed to the loop mode, a traveling-wave mode. The phase difference of 90 degree for the orthogonal electric fields is derived by embedding the slit in the ground plane and the CP radiation can be easily achieved. The measured and simulated results of S_{11} and AR agree well. The design procedures are presented.

2. ANTENNA DESIGN

Figure 1 shows the schematic diagram of the proposed CP GPS/DCS antenna. The proposed antenna configuration consists of a C-like monopole, one sleeve and one slit. The antenna is printed on an FR4 microwave substrate with thickness of 1.6 mm and relatively permittivity of 4.4. A 50-Ω microstrip-fed line with a width (W_t = 3 mm) is used to excite the antenna. An impedance transformer is inserted between the monopole antenna and the feeding line. Impedance matching is also optimized by cutting the copper ground plane. The C-like monopole is centrally placed at the end of the microstrip feeding line and the length of the monopole antenna is determined by a quarter wavelength at 2 GHz. Due to the interaction between the monopole and the ground plane, the length will decrease. Because of the bent structure, the impedance matching condition is poor. As similar as the design of adding a shorted parasitic wire [15], we add an inverted-L strip on the right side of the ground plane in

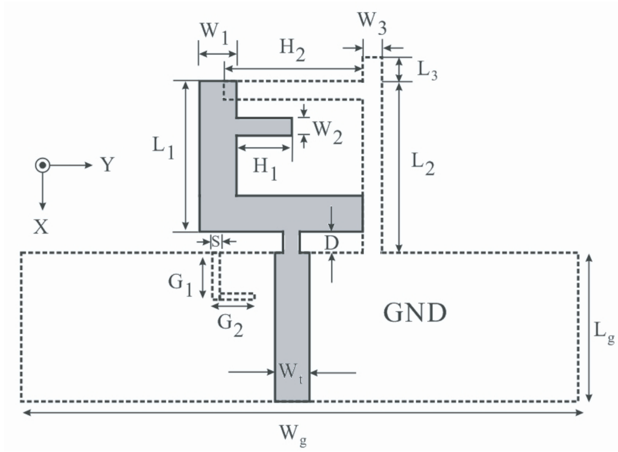


Figure 1. Schematic configuration of the proposed antennas.

order to improve the impedance characteristics. At the GPS band, the monopole and the inverted-L sleeve can be treated as the rhombic hula hoop [16], and the proposed antenna can have the current distribution of traveling-wave type on the loop, which has approximately a constant amplitude and linearly changing phase. The current distribution is changed by modifying the geometrical dimensions of the gap between the monopole and sleeve. To improve the phase difference of the two orthogonal electric fields and achieve the better circular polarization, an L-shaped slit is embedded in the ground plane on the left side of the feeding line. The slit width (S) is 1 mm. By tuning the geometrical parameters of the antenna, the characteristic parameters such as reflection coefficient (S_{11}) and axial ratio (AR) of the proposed antenna have been compared in order to optimize the antenna. Table 1 gives the geometrical parameters for the proposed CP quasi-loop antenna after optimization process. The antenna performance for the different topologies of the slit in the ground plane is compared. Finally, the size of the ground plane is tuned to study the effect on S_{11} and AR.

Table 1. Geometric parameters of the proposed antenna.

Parameter	W_{1a}	W_{1b}	W_3	L_1	L_{2a}	L_{2b}	H_1	H_2	D	G_1	G_2	L_g	W_g
Unit(mm)	4.5	2.3	2	15	17	4	8	13	2	6	6	22	80

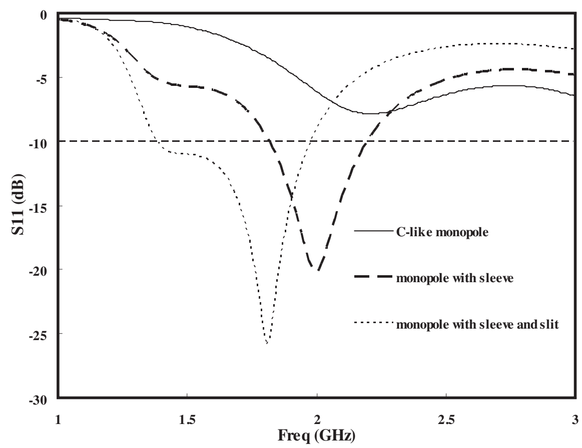


Figure 2. Comparison of the simulated S_{11} of the three tested antennas.

3. RESULTS

Figure 2 is the comparison of the simulated S_{11} of three tested monopole antennas, such as the C-like monopole, the monopole with the sleeve, and the monopole with the sleeve and slit. The parameters of the antennas are obtained using Ansoft High-frequency Structure Simulator (HFSS) simulation software in order to compare the improvement in the antenna bandwidth and circular polarization. From the results, the C-like monopole radiates little power into the space due to the poor matching condition at 2.2 GHz. The resonant band at 2.0 GHz can be obtained after adding the inverted-L grounded strip. The operating frequency is further shifted toward the lower frequency as the L-slit is embedded. The designs of the grounded strip and the L-slit also cause an increase in bandwidth, and a decrease in reflection coefficient levels.

Figure 3 shows the simulated axial ratio (AR) versus operating frequency for the three kinds of the above antennas, respectively. Although the AR of the C-like monopole is close to 3 dB, little power is radiated because of poor impedance matching condition at 1.4 GHz. Tuning of the antenna by use of the sleeve and slit is introduced to improve the AR and impedance bandwidth characteristics.

Figure 4 shows the simulated and measured reflection coefficient of the proposed antenna with the sleeve and slit. As can be observed from this figure, the measured center frequency and -10 dB S_{11} bandwidth are 1.76 GHz and 530 MHz (30.1%), whereas the center frequency and

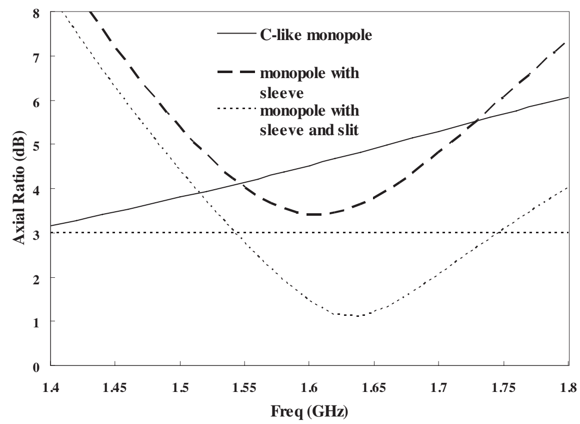


Figure 3. Comparison of the simulated AR of the three tested monopole antennas.

simulated bandwidth are 1.81 GHz and 600 MHz (33.1%). The slight discrepancy between the simulation and measurement results can be attributed to the finiteness of the ground plane, which causes a shift in the resonant frequency and to the fact that the response of the antennas is sensitive to the exact location of the microstrip feed, which is subject to alignment errors in the fabrication process.

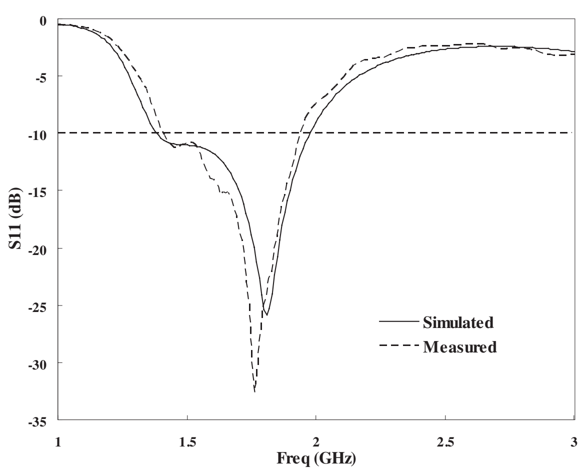


Figure 4. Comparison of the simulated and measured reflection coefficient of the proposed antenna.

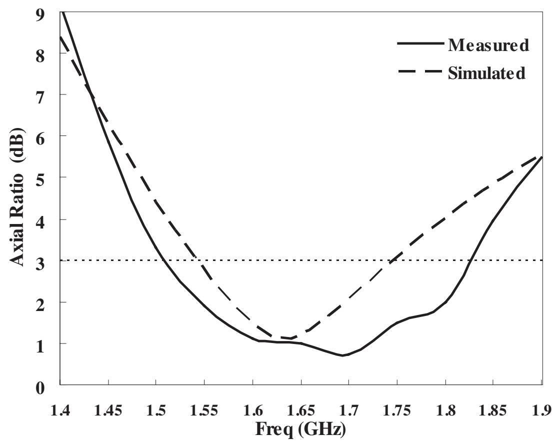


Figure 5. Comparison of the simulated and measured axial ratio of the proposed antenna.

The comparison of the simulated and measured AR of the proposed antenna is shown in Fig. 5. It is observed that the antenna attains a measured AR bandwidth (AR < 3 dB at broadside direction) of 19.2% (1.51–1.83 GHz), and a simulated AR bandwidth of 12.1% (1.55–1.75 GHz). It may be attributed to the reason that the phase difference of the two measured orthogonal E vectors is close to 90 degree over a wider frequency band. The measured AR bandwidth of the proposed antenna is much larger than the bandwidth specification (2 MHz bandwidth required) for GPS operation at 1.575 GHz.

The simulated and measured radiation patterns of the XZ- and YZ-planes of the proposed antenna at 1.57 and 1.80 GHz are presented in Fig. 6. The YZ-plane patterns are omni-directional and the XZ-plane patterns are 8-like. Due to the quasi-loop structure, the electric field on the horizontal segment of the antenna is strong and the magnitudes of the cross-polarized patterns are similar to the magnitude of the co-polarized patterns. The simulated gain and efficiency of the proposed antenna is shown in Fig. 7. The gains are about 1.95 and 1.15 dBi at 1.57 and 1.80 GHz. The efficiencies are larger than 80% over the operated band.

The distribution of the simulated surface current density of the antenna is shown in Fig. 8. From the results, due to the slit embedding in the ground plane, the induced current distributes along the slit and is helpful for the CP radiation, as expected. The distribution shows that the proposed antenna is excited by the loop mode, a travelling-wave mode, at 1.575 and 1.8 GHz. According the traveling direction

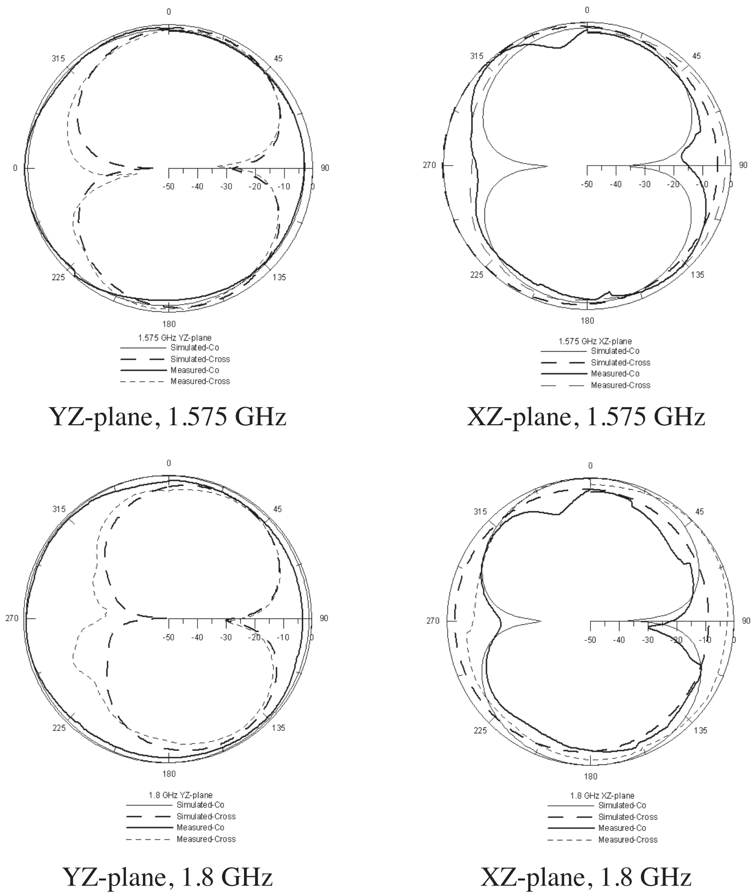


Figure 6. Simulated and measured radiation patterns of the XZ- and YZ-plane of the proposed antenna at 1.575 and 1.8 GHz.

of the simulated surface current, the type of the circular polarization of the proposed antenna is left-hand. However, the right-hand circular polarization can be derived by moving the sleeve to the left side of the ground plane and reversing the C-like antenna and the sleeve.

4. PARAMETRIC STUDY

In the previous sections, the performance of the CP quasi-loop antenna is presented. It is of practical interest to investigate the antenna performance when some of the geometrical parameters are changed.

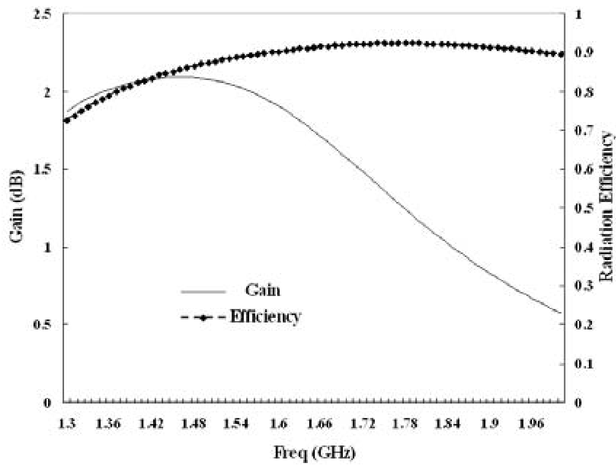


Figure 7. Simulated gain and radiation efficiency of the proposed antenna.

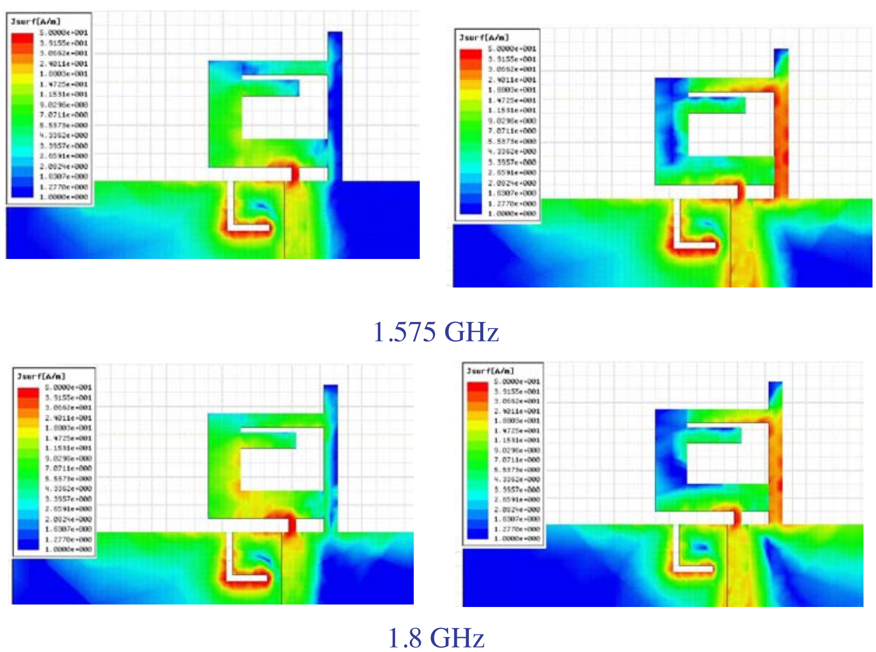
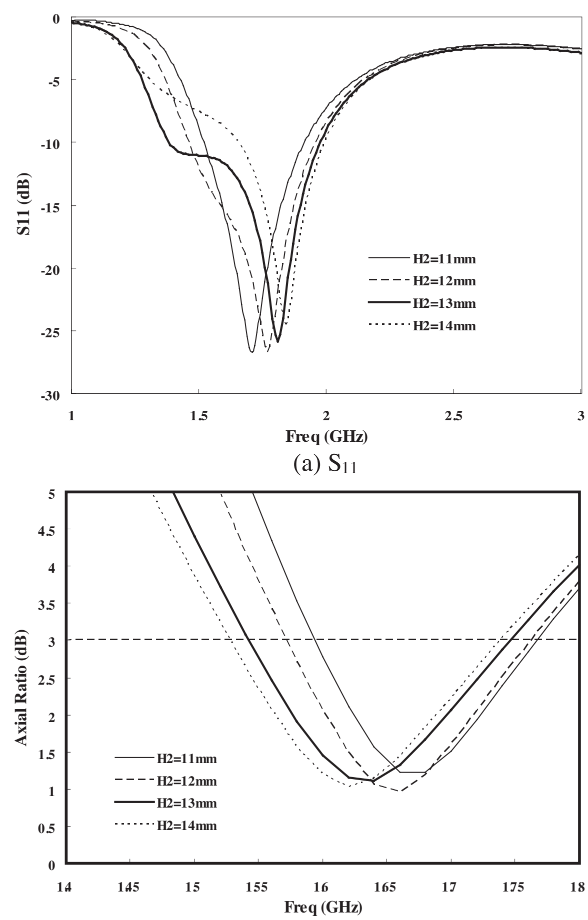


Figure 8. Distribution of the simulated surface current density of the antenna.

Here, the effects of tuning the inverted-L sleeve dimension on S_{11} and AR are presented. Meanwhile, the topology of the slit embedded in the ground plane is tested and compared.

4.1. Varying Length (H_2) of the Horizontal Segment of the Sleeve)

Figure 9 demonstrates the performance of the antenna when the length of the horizontal segment of the sleeve is varied. It is found that



(a) S_{11}

(b) AR

Figure 9. Performance of the antenna when the length (H_2) of the horizontal segment of the sleeve is varied.

changing the length could give frequency-moving effect to the antenna's S_{11} and AR bandwidths. It is observed that the impedance frequency, power level and AR bandwidth increase when the length varies from 11 to 14 mm. On the other hand, the impedance bandwidth and AR frequency decreases. In order to cover the operating frequency at the GPS band, length of H_2 is set to 13 mm.

4.2. Varying Open-stub Length (L_{2b})

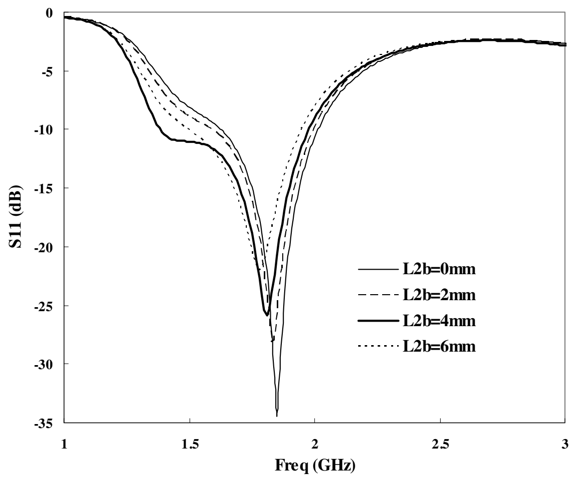
Figure 10 shows the comparison of S_{11} and AR of the antenna when the length of the open stub connecting with the sleeve is varied. As shown in the figure, the bandwidth and reflection coefficient level can be controlled by varying L_{2b}. It has significant effect on the impedance matching condition around 1.5 GHz. The reflection coefficient at the GPS band (1.575 GHz) is improved when increasing the length. Moreover, as L_{2b} is increased to 4 mm, the lower-band-edge frequency (when $S_{11} = -10\,\text{dB}$) decreases and the impedance bandwidth is increased by 57.9%. The reason of the bandwidth enhancement may be that the capacitance of the open stub cancels part of the inductance resulting from the thin antenna trace. At L_{2b} equal to 6 mm, the impedance characteristics become undesired and the impedance bandwidth decreases again.

4.3. Varying Length (L_{2a}) of the Vertical Segment

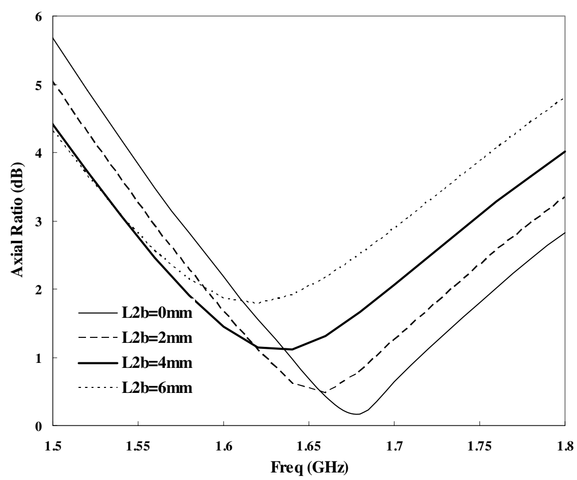
Figure 11 shows the comparison of S_{11} and AR when the length of the vertical segment of the sleeve is varied. From the simulated impedance characteristics (S_{11}), it is observed that the sleeve not only results in the CP performance but also affects the impedance bandwidth, especially at the GPS band. Although the axial ratio for the case of $L_{2a} = 17.3\,\text{mm}$ is more suitable for the CP performance at the GPS band, the impedance bandwidth does not cover the required band ($1575 \pm 2\,\text{MHz}$) for the GPS application.

4.4. Replacing the Slit Topology

Figure 12 shows the comparison of the simulated reflection coefficient and axial ratio of the quasi-loop antenna when changing the slit topology. The three slit topologies, including the L-slit, the inverted-L-slit and the I-slit, are shown in Fig. 12(c). The dimensions of the C-like monopole and inverted-L sleeve are fixed to the same values in Table 1. From the results of impedance characteristics, the lower-band-edge frequency, impedance matching condition and power level of the L-slit case are superior to the other cases. The obtained impedance

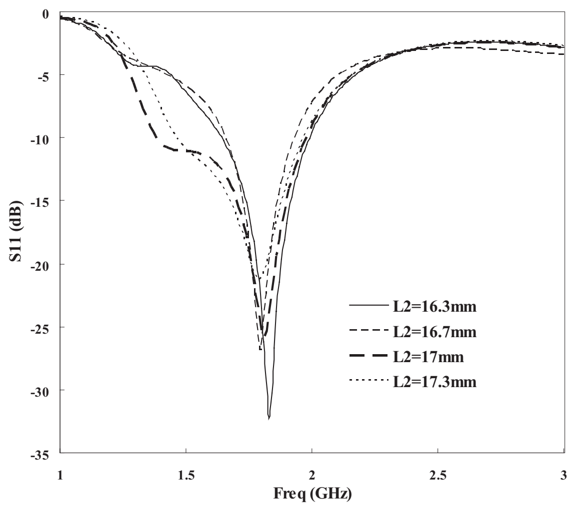


(a) S11

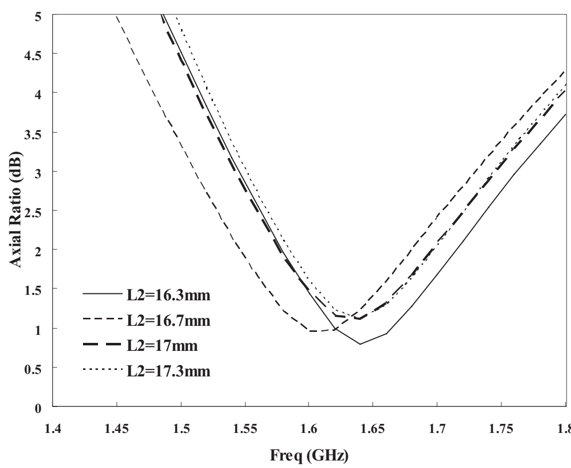


(b) AR

Figure 10. Comparison of S_{11} and AR of the antenna when the length (L_{2b}) of the open stub is varied.



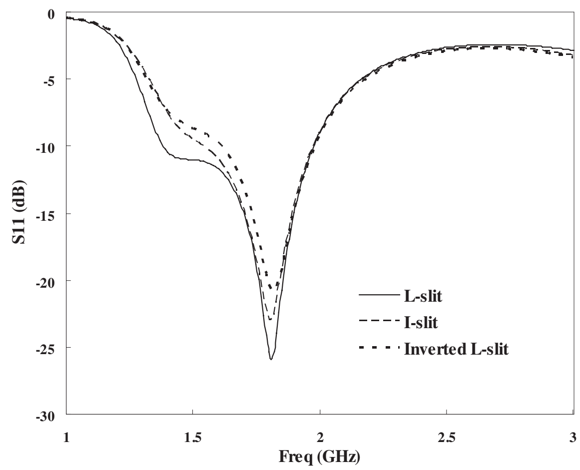
(a) S_{11}



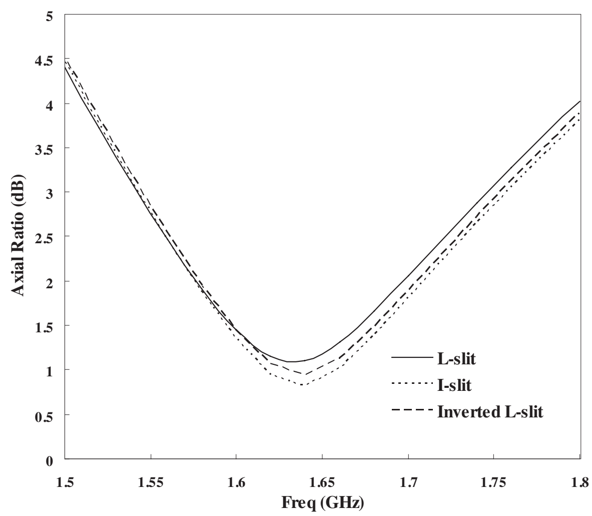
(b) AR

Figure 11. Comparison of S_{11} and AR when the length of the vertical segment of the sleeve is varied.

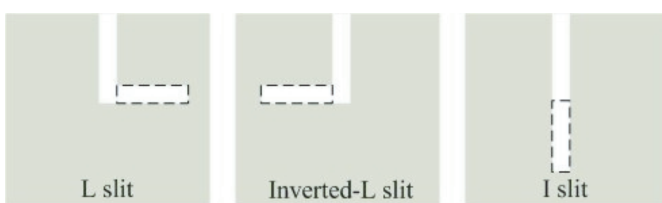
bandwidth for the L-slit case reaches 600 MHz (1.38–1.98 GHz), which covers the bandwidths of the GPS and DCS operations. However, the bandwidths for the inverted-L and I-slit cases are 370 MHz (1.61–1.98 GHz) and 440 MHz (1.54–1.98 MHz). From the AR results, the CP radiation for all cases has been excited. The AR bandwidth and AR frequency for the three cases are similar. It is mentioned that the



(a) S_{11}

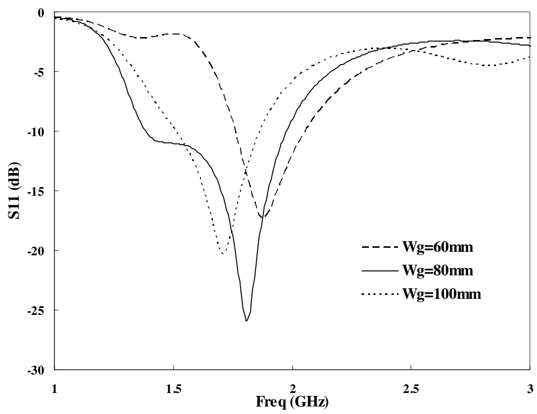


(b) AR

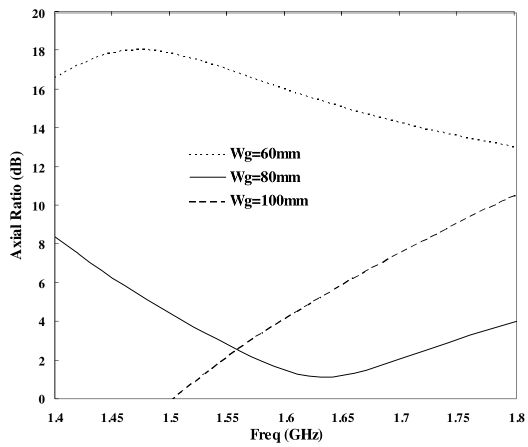


(c) Slit topology

Figure 12. Comparison of S_{11} and AR when changing the slit topology.



(a) S_{11}



(b) AR

Figure 13. Comparison of S_{11} and AR of the antenna when the length (Wg) of the ground plane is varied.

slit-embedding design may be a useful and stable method to excite the CP performance of the microstrip monopole antenna or the loop antenna.

4.5. Tuning the Size (Wg) of the Ground Plane

Figure 13 shows the comparison of S_{11} and AR of the antenna when the length (Wg) of the ground plane is varied. From the figures, it is found that the ground plane plays an important role on the radiation. The operated frequency of the antenna decreases when increasing the length. The improvement of the impedance bandwidth can be achieved by tuning the dimension of the ground plane.

5. CONCLUSION

This paper presents a circularly polarized loop-like antenna design with good performance for the applications of the GPS and DCS. By adding an inverted-L sleeve at the ground plane and tuning the gap dimensions, the loop mode can be excited. The CP performance is easily improved by embedding the slit in the ground plane. Future research will be studied in order increase the impedance bandwidth covering the CDMA operation.

ACKNOWLEDGMENT

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