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# Design and Simulation Based Studies of a Dual-Band Circularly-Polarized Square Microstrip Antenna

**Takafumi Fujimoto[1, *], Yuta Yoshitake[1], and Daisuke Yagyu[2]**

**Abstract**—A dual-band circularly-polarized microstrip antenna is proposed, and the antenna for GPS is designed. The radiation characteristics of the dual-band circular polarization are achieved by installing one pair of $L$-shaped slits at all edges of the square patch. The impedance matching in the dual band is tuned by an $L$-probe feed. The proposed antenna is effective and useful in the design for dual-band circularly-polarized operation.

## 1. INTRODUCTION

In global positioning system (GPS), both the L1 (center frequency $f_C = 1.575\,\text{GHz}$) and L2 ($f_C = 1.227\,\text{GHz}$) bands are used to reduce the amount of multipath error introduced into the receiver [1]. In the GPS, a circularly-polarized wave is used. In radio frequency identification (RFID), a circularly-polarized wave is used in the 900 MHz and 2.45 GHz bands in Japan. Moreover, circularly-polarized antennas are becoming popular in wireless communications such as Wi-Fi (IEEE.802.11 standard) because circular polarization can reduce the transmission loss caused by the misalignment between antennas of stationary and mobile terminals [2]. For these purposes, dual-band circularly-polarized small antennas are required. Some printed dual-band circularly-polarized antennas have been proposed [3–8]. However, most of them radiate a circularly-polarized wave to the bidirection (front and back sides). Therefore, the antennas cannot be installed on the body frame such as a vehicle, a ship or an airplane or on the wall of an indoor room. There are only a few printed dual-band circularly-polarized antennas with a unidirectional radiation pattern [1, 9, 10]. The design of dual-band circularly-polarized antennas for GPS seems to be especially difficult because the ratio of the two operating frequencies is very small (1.575 GHz/1.227 GHz = 1.28).

In this paper, a dual-band circularly-polarized square microstrip antenna (MSA) is proposed. In GPS, antennas have to receive signals from at least four satellites at any one time [11]. Therefore, it is desirable that the antenna for GPS radiates at wide angles. Since MSA has a radiation pattern with relatively wide angles, the MSA is suitable for a GPS antenna. In [1], a dual-band GPS antenna with wide radiation pattern has been designed. However, the MSA in [1] is excited by a dual-feed. The design for the dual-fed circularly-polarized MSA is difficult compared to a single-fed MSA because the dual-fed circularly-polarized MSA needs a power divider with a 90° phase shift. The dual-band circularly-polarized MSA proposed in this paper is excited by a single-feed. The geometry of the patch conductor is square with one pair of $L$-shaped slits at each edge to miniaturize the patch's size and achieve a circularly polarized wave in the dual band. In order to tune the impedance matching in the two frequency bands, an $L$-probe feed is used [12]. The design procedures of the two operating frequencies and the minimum axial ratio in the two frequency bands are obtained with simulations. The operational principle of the antenna is clarified by the simulated electric current distributions. For

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* Corresponding author: Takafumi Fujimoto (takafumi@nagasaki-u.ac.jp).
[1] Graduate School of Engineering, Nagasaki University, Nagasaki 852-8521, Japan. [2] Center for Information and Communication Technology, Nagasaki University, Nagasaki 852-8521, Japan.

the calculations in this paper, the simulation software package FEKO ver. 6.2, which is based on the method of moments, is used. In order to ascertain the accuracy of the simulated results, the simulated axial ratio, return loss and radiation patterns are compared to experimental data.

## 2. ANTENNA DESIGN

Figure 1 shows a dual-band circularly-polarized square MSA. The geometry of the patch conductor is a square with one pair of $L$-shaped slits at each edge. The width of the $L$-shaped slits is fixed at $S_t = 0.5$ mm. In order to radiate circularly polarized waves in the two frequency bands, the dimension of the $L$-shaped slits along the $x$-axis is different from that along the $y$-axis. In order to tune impedance matching in the two frequency bands, the antenna is excited by an $L$-probe feed which lies at the diagonal of the square patch conductor. The thickness and relative dielectric constants of each dielectric layer are $h_1 = 3.2$ mm and $h_2 = 1.6$ mm and $\varepsilon_{r1} = \varepsilon_{r2} = 3.8$, respectively. The loss tangent of both the dielectric substrates is 0.022. The dimension of the dielectric substrate is fixed at $W_g \times W_g = 70\,\text{mm} \times 70\,\text{mm}$.

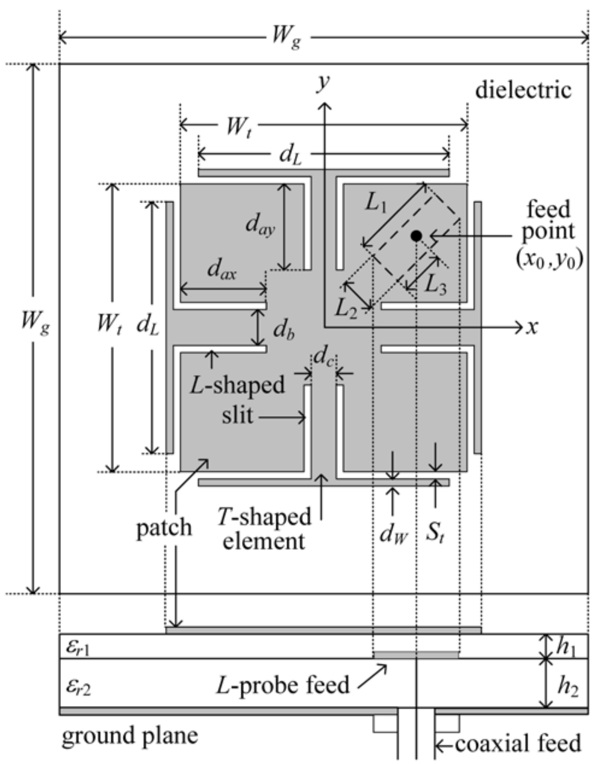


**Figure 1.** Geometry of a proposed antenna.

## 3. ANTENNA CHARACTERISTICS

A dual-band circularly-polarized MSA for the GPS is designed according to the parametric studies in the next section. The optimal dimensions of the proposed antenna are as follows: $W_t = 40$, $d_{ax} = 13.49$, $d_{ay} = 12.01$, $d_b = 2.44$, $d_c = 1.56$, $d_L = 35.5$, $d_W = 1.07$, $(x_0, y_0) = (9, 9)$, $L_1 = 18.0$, $L_2 = 9.0$, $L_3 = 8.49$ (unit: mm). The width of the patch is equal to $41.12\,\text{mm} = 0.22\lambda_{1.575} = 0.17\lambda_{1.227}$ ($\lambda_f =$ the wavelength at $f$ GHz).

Figures 2(a) and (b) show the simulated return loss and axial ratio of the designed antenna, respectively. The measured results are also shown for comparison. The antenna was made of a FR-4 dielectric substrate. The relative errors of the frequency giving the minimum axial ratio are 0.52% and 0.67% in the L1 and L2 bands, respectively. The relative error is defined as | simulated value —

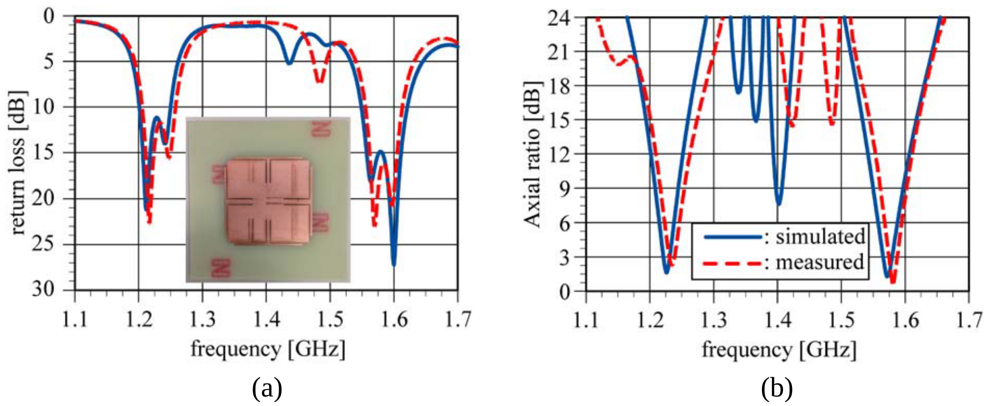


**Figure 2.** Simulated and measured return losses and axial ratios. (a) Return loss. (b) Axial ratio ($\theta = 0^\circ$).

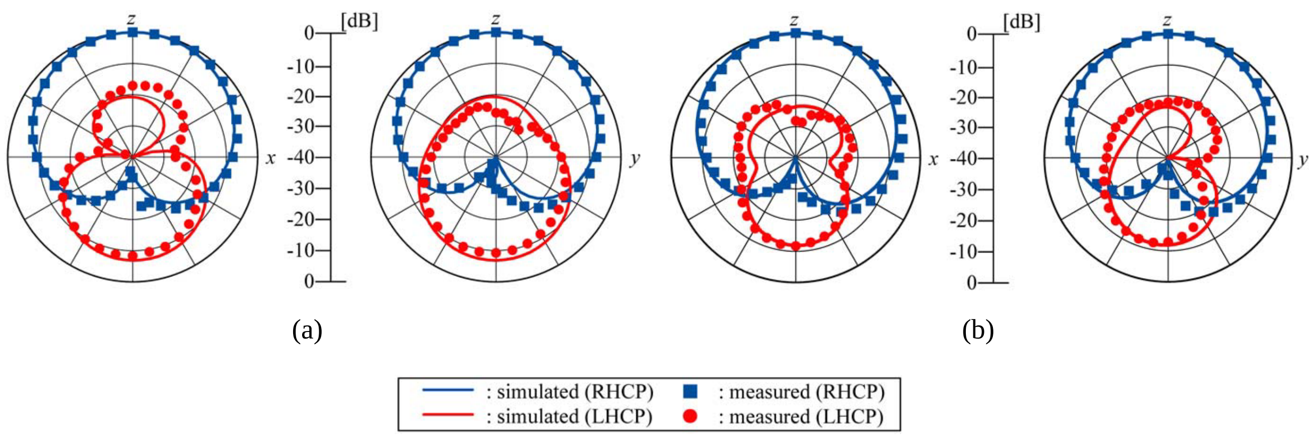


**Figure 3.** Simulated and measured radiation patterns. (a) L2 band. (b) L1 band.

measured value|/measured value ×100 [%]. The simulated return loss and axial ratio agree with the measured results. The simulated and measured bandwidths of 10 dB — return loss with 3 dB — axial ratio in the L1 band are 14.0 MHz and 13.1 MHz, respectively. Those in the L2 band are 10.0 MHz and 8.1 MHz. Both the simulated and measured bandwidths satisfy the specifications (4 MHz) of the GPS.

Figures 3(a) and (b) show the simulated and measured right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) radiation patterns normalized by the maximum value of the RHCP in the $xz$- and $yz$-planes at the frequencies giving the minimum axial ratio. The simulated radiation patterns agree with the measured results. For the GPS, it is required to have wide beamwidths with 3 dB-axial ratio. The simulated beamwidth at the frequency giving the minimum axial ratio in the L1 band is 180° in the $xz$-plane and 174° in the $yz$-plane. Those in the L2 band are 178° and 136° in the $xz$-plane and $yz$-plane, respectively. The antenna radiates circularly-polarized wave at wide angles for both bands.

Figures 4(a) and (b) show the gain and efficiency for changes of the loss tangent ($\tan\delta$) of the dielectric substrate, respectively. The simulated maximum gains are 0.51 dBi and −0.42 dBi at the frequency giving the minimum axial ratio in the L1 and L2 bands, respectively. As the loss tangent increases, the dielectric loss also increases. Therefore, the gains and efficiencies decrease. Since the loss tangent of the FR-4 dielectric substrate is relatively big ($\tan\delta = 0.022$), the gain of the designed MSA becomes less than 0 dBi. However, the gains and efficiencies can be improved by using the dielectric substrate with a low dielectric loss tangent such as Glass-fiber-PTFE.

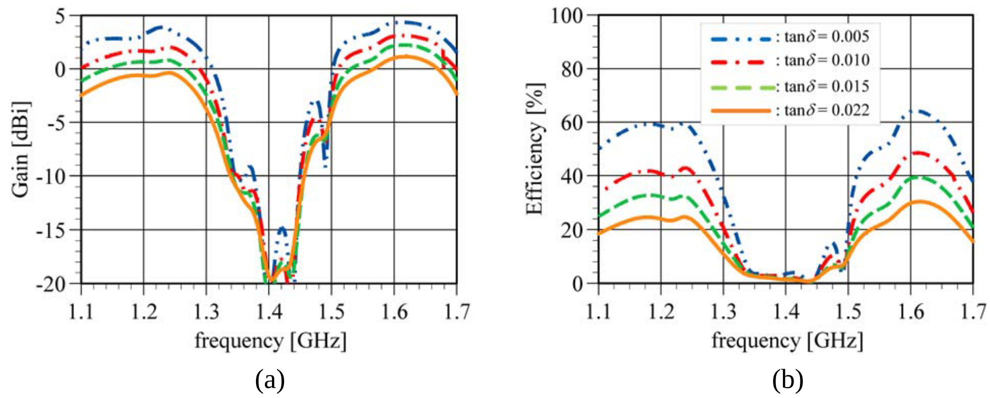


**Figure 4.** Simulated gain and efficiency for changes of the loss tangent ($\tan\delta$). (a) Gain. (b) Efficiency.

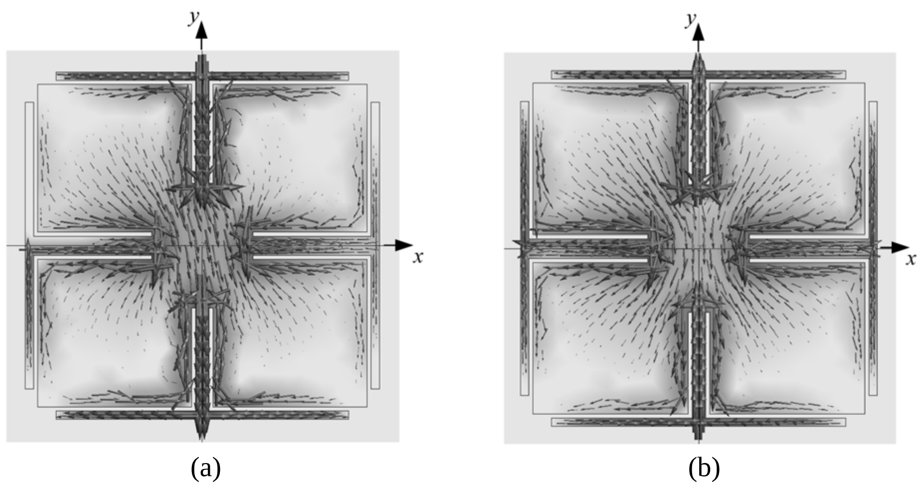


**Figure 5.** Simulated electric current distributions at $\omega t = 90°$. (a) L2 band. (b) L1 band.

## 4. OPERATIONAL PRINCIPLE AND PARAMETRIC STUDIES

Figures 5(a) and (b) show the electric current distributions at the frequencies giving the minimum axial ratios. Time instant is $\omega t = 90°$ for both frequencies. In both of the bands, the electric currents concentrate at the $T$-shaped elements and at the edges of the patch around the $L$-shaped slits. In the L2 band, the directions of the electric currents on the $T$-shaped elements along the $y$-axis are the same as those on the patch between the $T$-shaped elements, while in the L1 band, the electric currents on the $T$-shaped elements and on the patch between the $T$-shaped elements flow to the directions opposite each other. The electric currents along the $x$-axis at $\omega t = 0°$ have the same distributions as those along the $y$-axis at $\omega t = 90°$ as shown in Figures 5(a) and (b) (but are omitted in this paper). Therefore, in the L2 band, the antenna resonates when the sum of the lengths of the two $T$-shaped elements along the $x$- or $y$-axes, and the length of the patch between the two elements is equal to approximately a half wavelength. In the L1 band, the antenna resonates when the sum of the lengths of the two $T$-shaped elements is equal to approximately a half wavelength. This means that the influence of the length of the $L$-shaped slit on the operational frequency in the L1 band is greater than that in the L2 band. By the electric current distributions, the relationship between the sizes of the antenna patch and $T$-shaped elements, and the wavelength in the L2 band is given as follows;

$$\frac{1}{2}d_L + W_T + \frac{1}{2}d_L \simeq \frac{1}{2}\lambda_{g1.227}. \quad (1)$$

Moreover, the relationship between the size of the $L$-shaped elements and the wavelength in the L1 band is given by the following equation.

$$\frac{1}{2}d_L + d_{ax} + d_{ax} + \frac{1}{2}d_L = \frac{1}{2}d_L + d_{ay} + d_{ay} + \frac{1}{2}d_L \simeq \frac{1}{2}\lambda_{g1.575} \quad (2)$$

where, $\lambda_g$ is the wavelength in the dielectric substrate.

Figure 6(a) shows the difference between the frequency giving the best axial ratio and the center frequency $f_c$ (= 1.227 GHz in the L2 band and 1.575 GHz in the L1 band) for changes of the slits' length $d_{ax}$ (= $d_{ay}$). Figure 6(b) shows the case for changes of the $T$-shaped elements' width $d_W$. As the slits lengthen, the path length of the electric current also lengthens. Therefore, as the length of the slits increases, the frequencies shift to lower frequency range. As mentioned in the previous paragraph, it is confirmed that the lengths of the slits $d_{ax}$ and $d_{ay}$ influence the frequency in the L1 band greatly compared with that in the L2 band. On the other hand, the frequency in the L2 band can be controlled at a wide frequency range compared with that in the L1 band using the width $d_W$. The two operating frequencies can be tuned using mainly these two geometric parameters.

Figure 7(a) shows the axial ratios for changes of the ratios of the widths $d_b$ and $d_c$ between the two $L$-shaped slits at $d_{ax}/d_{ay} = 1.0$ ($d_{ax} = d_{ay} = 12.75$ mm). In the case of $d_{ax}/d_{ay} = 1.0$, the minimum axial ratio is given at around $d_c/d_b = 0.65$ in the L1 band and around $d_c/d_b = 0.69$ in the L2 band. This means that the antenna cannot radiate the circularly-polarized wave in the dual band in the case of $d_{ax}/d_{ay} = 1.0$. Figure 7(b) shows the axial ratio at $d_{ax}/d_{ay} = 1.123$ ($d_{ax} = 13.49$, $d_{ay} = 12.01$ mm). As shown in Figure 7(b), the minimum axial ratios are given at the same ratio ($d_c/d_b = 0.65$) in the L1 and L2 bands. The averaged length ($(d_{ax} + d_{ay})/2$) at $d_{ax}/d_{ay} = 1.123$ is equal to that at $d_{ax}/d_{ay} = 1.0$. In this case, the differences between the frequencies giving the best axial ratios at $d_{ax}/d_{ay} = 1.123$ and

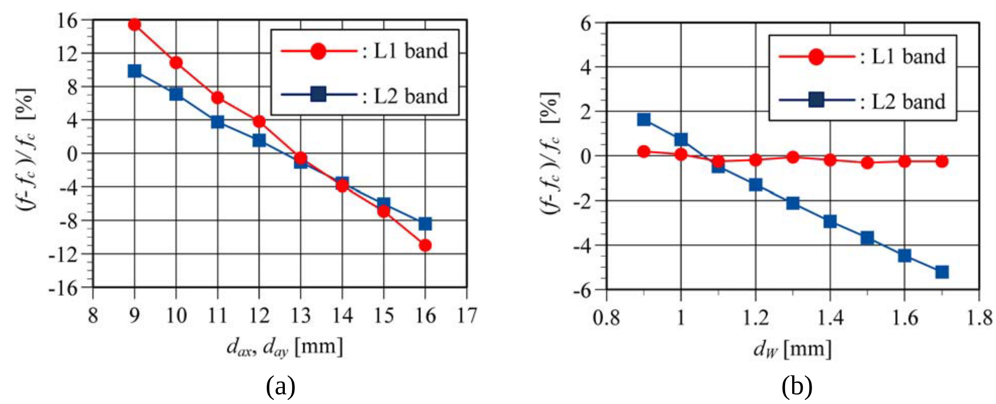


**Figure 6.** Differences from center frequency. (a) For changes of $d_{ax}$ (= $d_{ay}$). (b) For changes of $d_W$.

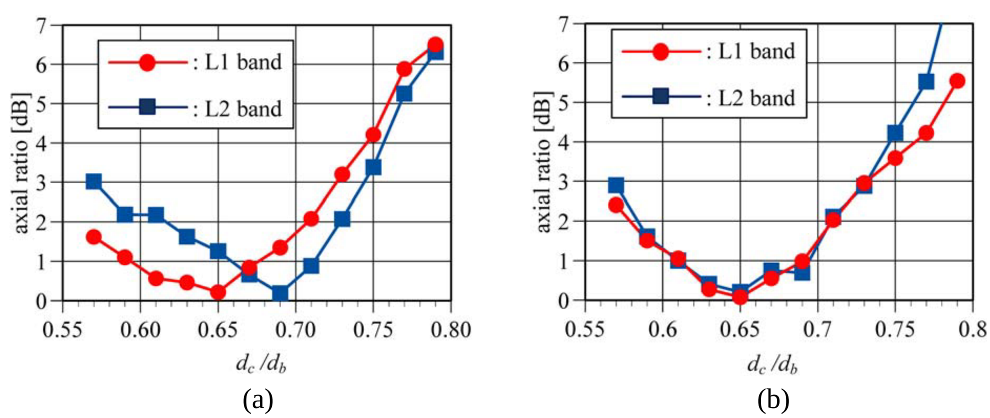


**Figure 7.** Axial ratios for changes of $d_c/d_b$. (a) At $d_{ax}/d_{ay} = 1.0$. (b) At $d_{ax}/d_{ay} = 1.123$.

$d_{ax}/d_{ay} = 1.0$ are very small for both bands. Therefore, the axial ratios in the two frequency bands can be adjusted by the ratios $d_c/d_b$ and $d_{ax}/d_{ay}$ while keeping the two frequencies giving the best axial ratio.

Design procedure for dual-band circularly-polarized MSA can be obtained by the parametric studies mentioned above. At first, the initial sizes of the patch, $T$-shaped elements and $L$-shaped slits are determined by Equations (1) and (2). Next, the size $W_t$ of the square patch and the lengths $d_L$ and $d_{ax}(= d_{ay})$ of the $L$-shaped slits are adjusted to tune the center frequency in the L1 band. After that, the width $d_W$ of the $T$-shaped elements is adjusted to tune the center frequency in the L2 band. Then, the feed point $(x_0, y_0)$, length $L_1$, width $L_2$, and location $L_3$ of the $L$-probe feed are adjusted to tune the impedance matching for both band. At last, the axial ratios in the two frequency bands can be adjusted by the ratios $d_c/d_b$ and $d_{ax}/d_{ay}$. The $L$-shaped slits make adjustments of axial ratios in the dual band and the two operational frequencies much easier. Therefore, the proposed antenna is effective and useful in the design for dual-band circularly-polarized operation.

## 5. CONCLUSION

A dual-band circularly-polarized MSA was proposed for the GPS. The operational principles of the antenna were discussed using the electric current distributions. Moreover, the design procedure for dual-band circularly-polarized operation was obtained. The return loss, axial ratio and radiation pattern were calculated by simulation software and compared with measured results. The good agreement between the calculations and measurements confirms the results of this work.

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