

# Circularly Polarized Frequency Controllable Microstrip Patch Antenna Using Partial Dielectric Filling

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## 1. Introduction

Microstrip antennas [1] have a flat structure composed of a compact and lightweight substrate and are used for various radio connections such as satellite broadcasting and a local area network (LAN) and mobile communications like an airplane, a car, and a cellular phone. In recent years, a service of radio communication systems is being diversified. A variety of these usages require a reconfigurable antenna operating at different frequencies and polarization, and being scanned as well. The reconfigurable antennas using the mechatronics technologies such as a motor, a piezo-electric actuator, and MEMS (Micro-Electro-Mechanical-System) have been developed [2]-[4]. These antennas have a feature of low loss, low cost, and low power consumption although they show a slow response time of the order of millisecond comparing with those made of semiconductor [5].

A patch antenna of interest here is one of the typical microstrip antennas. The controllability of the operation frequency, beam scanning, and polarization of the antenna have been reported [6]-[9]. The patch antenna usually consists of a patch, a dielectric substance layer, and a ground plane. A high permittivity material is used for the dielectric substance layer in order to make the antenna small [10]. In this case, a frequency was fixation, and the antenna operates for linear polarization. We reported the patch antenna that the dielectric substance layer was air into which a high permittivity material mechanically movable was partially inserted [11]. In this case, the resonant frequency of the antenna was controllable for linear polarization.

In this paper, we propose a circularly polarized patch antenna using partial dielectric filling whose resonant frequency is controllable. We describe a design of the proposed antenna using the FDTD (Finite Difference Time Domain) method and experimental results.

## 2. Structure of the proposed antenna

Figure 1 shows a structure of the proposed antenna. The antenna consists of a square patch, a ground plane, and a dielectric substance partially filled in air between the patch and the ground. The square patch side length is  $L$ , the ground side length is  $L_g$ , the space between the patch and the ground is  $h$ , and the filling dielectric substance side lengths and thickness are  $L_1$  and  $L_2$ , and  $t$ . A feed point marked as  $F$  is placed at a distance of  $L_f$  from the center of the patch in the  $x$  direction. In the case of  $t < h$ , the dielectric substance inserted into the air layer is mechanically movable. Amounts of the insertion into the patch region are  $a$  in the  $x$ -axis and  $b$  in the  $y$ -axis.

## 3. Design of the antenna

We analyzed the proposed antenna using the FDTD method with an inequitable mesh. Parameters used for the calculation were  $L=10\text{mm}$ ,  $L_g=122\text{mm}$ ,  $L_f=2.1\text{mm}$ ,  $h=0.68\text{mm}$ ,  $L_1=10\text{mm}$ ,  $L_2=12\text{mm}$  and  $t=0.5\text{mm}$ . The relative permittivity of the dielectric plate for filling was 9.7. The patch and the ground were assumed to be a complete conductor. A Gaussian pulse was excited through the feeder. The total number of the time steps was 40000. The Mur's two-dimensional absorbing boundary was used as an absorbing boundary [12].

Figure 2 shows the axial ratio as a function of the frequency for the wave observing from the broadside when the insertion  $a$  was fixed with 2.9mm and the insertion  $b$  was changed. As increasing the insertion  $b$ , the frequency minimizing the axial ratio decreases. The smallest axial ratio was 0.31dB for  $b=9.1$ mm. In this case, the phase difference between the orthogonalized fields was +88.6 degrees, the result of which indicates the antenna practically operates as a circularly polarized antenna. Figure 3 plots the  $zx$ -plane radiation pattern. The radiation pattern shows the similar pattern of the half-wave length dipole circularly polarized antenna although an asymmetric pattern appears in the angle over  $\pm 60$  degrees. The cross-polarization ingredient was less than -30dB at the broadside. Thus, the patch antenna with the dielectric plate inserting into the air layer asymmetrically to the patch operates as a circularly polarized antenna.

Next we investigate the frequency controllability of the proposed antenna. Here we changed the insertion lengths  $a$  and  $b$  to find out the frequency for the minimum axial ratio. Figure 4 shows the calculation results of the relation between the insertion lengths  $a$  and  $b$  when the axial ratio took place the minimum value. When the insertion  $a$  lies between 0.5mm and 1.5mm,  $b$  changes largely; however, when the insertion  $a$  exceeds 2.0mm, the change in the insertion  $b$  tends to become small. The axial ratios were 0.5dB or less in all cases. Figure 5 shows the frequency operating as a circularly polarized antenna for the insertion length  $a$ . As increasing the insertion length  $a$  from 0.5mm to 5.0mm the operation frequency linearly changed from 9.94GHz to 12.76GHz. VSWR (voltage standing wave ratio) was 2 or less for the frequency ranging from 11.04GHz to 11.87GHz. Thus, the frequency of the patch antenna operating as a circularly polarized antenna is varied by partially inserting the dielectric plate into the air layer.

## 4. Experiment result

We checked the proposal by fabricating the actual antenna with the same parameters as those of the explanation. The dielectric substance was alumina ( $\epsilon_r=9.7$ ). The conducting patch was a copper plate with a thickness of 0.2mm and the ground plane was aluminium (200mm $\times$ 200mm $\times$ 5mm). The alumina dielectric plate was mechanically moved with a linear actuator.

First, the radiation pattern of the fabricated antenna was measured. The insertion length  $a$  was fixed with 4.2mm and the frequency was fixed with 10.85GHz. Figure 6 shows the relation between the axial ratio of the antenna measured at the broadside and the insertion length  $b$ . The axial ratio took the minimum value of 0.26dB at the insertion length  $b$  of 8.03mm. The  $zx$ -plane radiation pattern for this antenna is shown in Fig. 7, the result of which was similar to that of the calculation. The antenna gain at the broadside was 7.9dBi and the return loss was -18.1dB.

Next, we investigated the frequency controllability. Values of  $a$  and  $b$  for the optimum operation of circular polarization were searched by moving the alumina plate. Figure 8 shows the relation between the insertion lengths  $a$  and  $b$  for the circularly polarized operation. The axial ratios were 0.5dB or less for the insertion length  $a$  from 1.0mm to 5.5mm. The measured result indicated the similar tendency as the calculation. Figure 9 shows the frequency operating as a circularly polarized antenna for the insertion length  $a$ . As expected from the analysis, the frequency was varied by changing the insertion length. The operation frequency changed about 10 percent from 10.64GHz to 11.83GHz within VSWR of 2 or less. Thus, the frequency operating as a circularly polarized patch antenna can be varied by changing the inserting position of the dielectric plate in the air layer although there exists some difference between the calculated and experimented results.

## 5. Conclusion

In this paper, we proposed the circularly polarized frequency controllable patch antenna using the dielectric plate partially filled in the air gap between the patch and the ground plane. The proposed antenna was designed using the FDTD method, and the operation as a circularly polarized antenna and the frequency controllability were experimentally confirmed. The obtained range of the frequency variation was 10 percent within VSWR of 2 or less at the 10GHz band. We are now planning a realization of a switching of the right-handed and the left-handed circular polarization.

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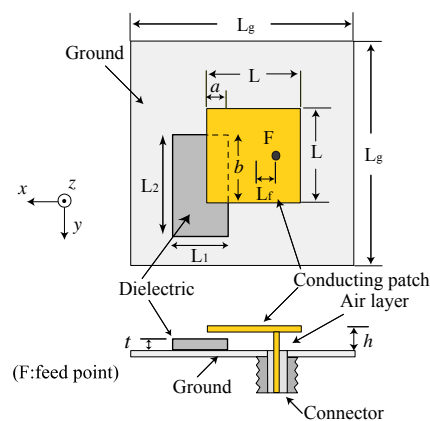


Fig.1. Structure of the proposed antenna.

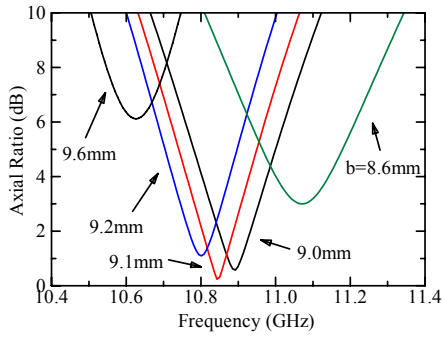


Fig.2. Calculated frequency characteristics of axial ratios.

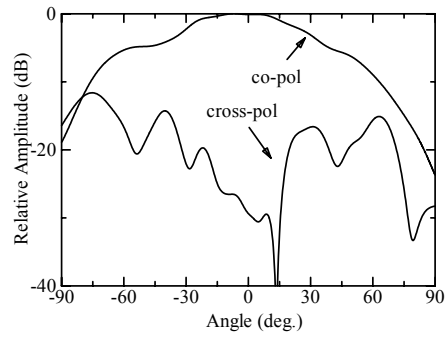


Fig.3. Calculated  $zx$ -plane radiation pattern.

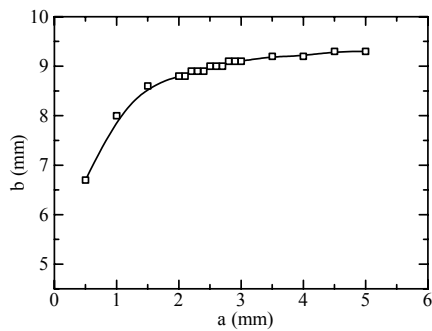


Fig.4. Relation between  $a$  and  $b$  for the optimum condition (calculation).

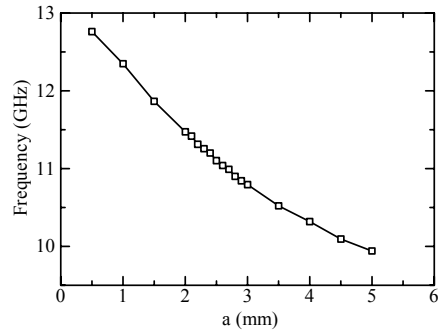


Fig.5. Calculated operating frequency vs.  $a$ .

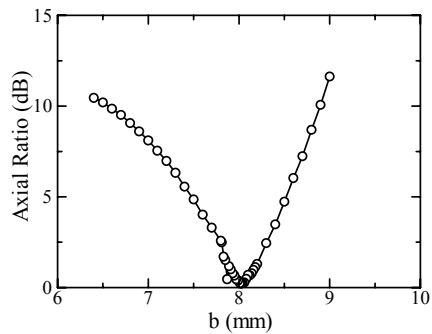


Fig.6. Measured axial ratio vs.  $b$ .

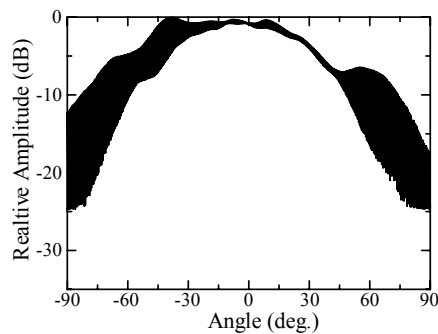


Fig.7. Measured  $zx$ -plane radiation pattern.

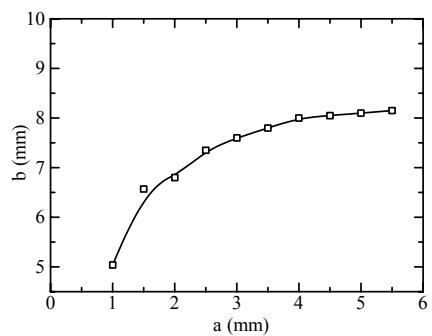


Fig.8. Relation between  $a$  and  $b$  for the optimum condition (measurement).

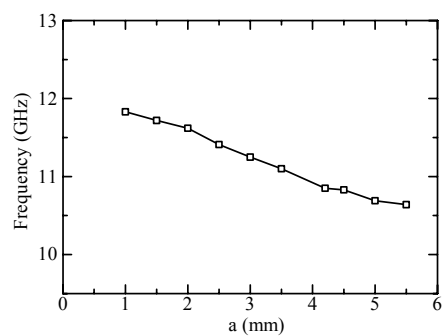


Fig.9. Measured operating frequency vs.  $a$ .