Circularly Polarized Microstrip Patch Antenna With Wide Tunability Range

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1. Introduction

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. A patch antenna of interest here is one of the typical microstrip antennas. The frequency control of the patch antenna was reported in 1982 using a semiconductor device [1]. Heretofore, the tunable antenna of the linearly polarized wave has been studied a lot. In recent years, the frequency control of the circularly polarized patch antenna has been achieved by using the ferrite [2], the semiconductor [3], and the mechatoronics technology [4]. Here, the reconfigurable antennas using the mechatoronics technologies such as a motor, a piezo-electric actuator, and MEMS (Micro-Electro-Mechanical-System) have been developed. 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 antennas incorporated with semiconductor devices. We proposed a circularly polarized patch antenna using partial dielectric filling whose resonant frequency is controllable using mechatoronics technology [5]. The control of the operation frequency was able to obtain ten percents by the experiment.

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

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 dielectric substances partially filled in air between the patch and the ground plane. Two dielectric substances are partially inserted on the opposite side of the patch. The dielectric substance (1) is inserted in asymmetry on the patch edge, and the dielectric substance (2) has been inserted in symmetry. The dielectric substance (1) generates the circularly polarized wave [5], and the dielectric substance (2) does operation to obtain the impedance matching. 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 thickness is 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 of the dielectric substance (1) are $\boldsymbol{a}$ in the x-axis and $\boldsymbol{b}$ in the y-axis. The insertion amount of other dielectric substance (2) is $\boldsymbol{c}$ in x-axis.

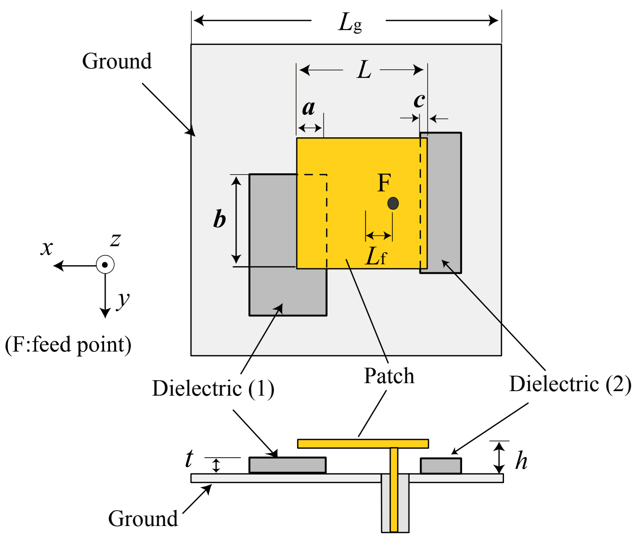

Figure 1: Structure of the proposed antenna.

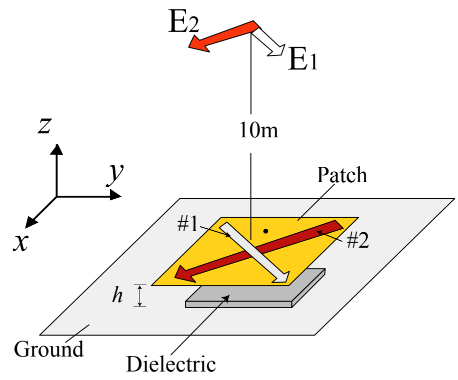

Figure 2: Operation of the antenna.

3. Simulated results

We analyzed the proposed antenna using the FDTD method with an inequitable mesh. Parameters used for the calculation were L=9mm, L_g=122mm, L_f=2.3mm, h=0.6mm, and t=0.5mm. 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 20000. The Mur's second-order absorbing boundary was used as an absorbing boundary.

The circularly polarized wave is the same amplitude between the orthogonalized fields and the phase difference is 90 degrees. Figure 2 shows the explanation of the antenna operation for the case that the dielectric substance is inserted into one side at the corner. The modes of spatially orthogonal #1 and #2 appear being able to resolve the degeneracy of the leading mode when the dielectric substance is inserted in the patch. E_1 and E_2 are shown an electric field of 10m from the patch, and correspond to #1 element and #2 elements, respectively. Figure 3 shows a frequency characteristics of the amplitude and the phase difference when the insertion length were $\boldsymbol{a}$=0.6mm and $\boldsymbol{b}$=7.6mm. The left-hand figure shows the amplitude, and the right-hand figure shows a phase difference. In the left figure, #1 mode feels much more permittivity than #2 mode. Therefore, E_1 operates by a frequency that is lower than E_2. The amplitude of E_1 and E_2 was corresponding by 13.385GHz. In that case, the phase difference in a right-hand figure shows 90.11 degrees. The smallest axial ratio was 0.08dB for 13.385GHz and return loss was -13.07dB. The 3dB axial-ratio bandwidth was 195MHz from 13.29GHz to 13.485GHz. Thus, the patch antenna with the dielectric plate inserting into the air layer asymmetrically to the patch operates as a circularly polarized antenna.

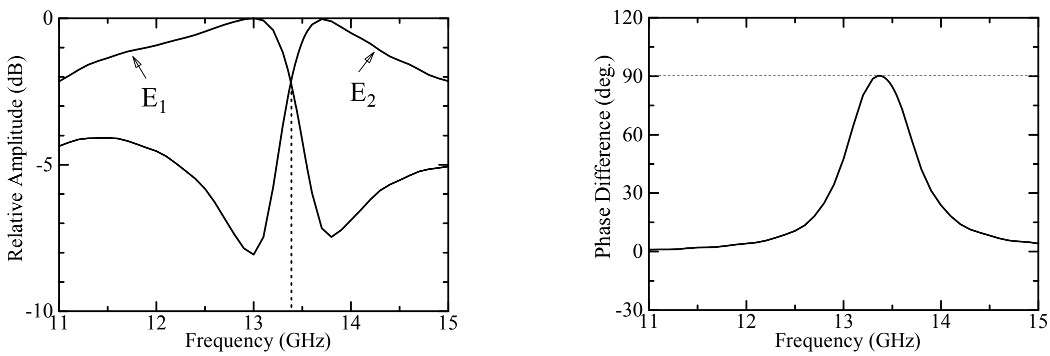

Figure 3: Frequency characteristics of amplitude and phase difference.

Figure 4 plots the *zx*-plane radiation pattern of E-plane and cross polarization components. The radiation pattern shows the similar pattern of the half-wave length dipole antenna although an asymmetric pattern. The amplitude of the broadside direction almost accords.

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 for the case that the dielectric substance (1) is inserted into one side. Figure 5 shows the frequency response of return loss when changing the optimum insertion lengths. The black circle in this figure is the operating frequency that the axis ratio becomes the minimum. The operating frequency of the antenna has shifted to a low frequency side by inserting the dielectric material. When the insertion of the dielectric substance is increased 1.5mm or more, the reflection of the antenna is increased. In the insertion length ***a***=3mm, the return loss was -1.9dB at 10.52GHz. Thereupon, the dielectric substance (2) is inserted in the edge of the patch near the feeding point. The impedance matching becomes possible because the current distribution of the patch becomes symmetry. Figure 6 shows the frequency response of return loss when changing the optimum insertion lengths. In ***a***=3mm, the return loss was ameliorable to -14.5dB at 10.4GHz by insertion of the dielectric substance (2). Other insertion lengths were ***b***=8.5mm and ***c***=0.4mm. The circle in the figure is showing the frequency of the circularly polarized wave and VSWR (voltage standing wave ratio) was 2 or less in all insertion positions. Figure 7 shows the relation between the insertion lengths ***a***, ***b*** and ***c***. When the insertion ***a*** lies between 0.2mm and 1mm, ***b*** changes largely; however, when the insertion ***a*** exceeds 1.5mm, the change in the insertion ***b*** tends to become small. In the case of the both sides insertion, ***b*** almost maintains the same value by increase of ***a***, and ***c*** tends to increase. Figure 8 shows the frequency characteristics of axial ratios when the dielectric substance inserts one side and both sides. The axial ratios were 1.25dB or less and the 3dB axial-ratio bandwidth was 89.3MHz from 243.5MHz. Figure 9 shows the relation between the insertion length ***a*** and the operating frequency. As increasing the insertion length ***a*** from 0.2mm to 6.5mm, the operation frequency changed from 14.172GHz to 9.056GHz and VSWR was 2 or less. Figure 10 shows the frequency characteristics of the antenna gain. The antenna gain changed from 9.1dBi to 5.3dBi. 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.

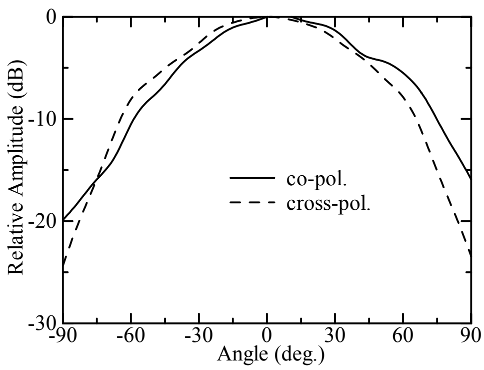

Figure 4: Radiation pattern of E-plane.

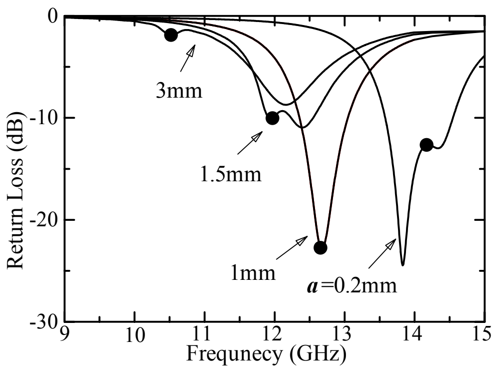

Figure 5: Return loss (One side)

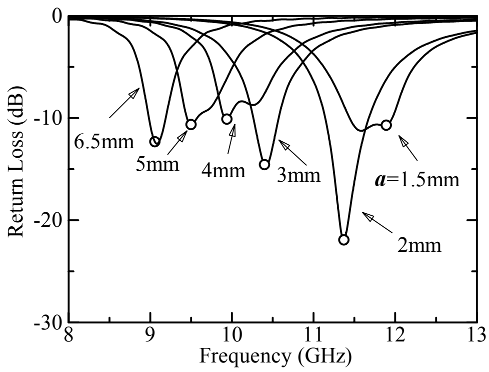

Figure 6: Return loss (Both sides).

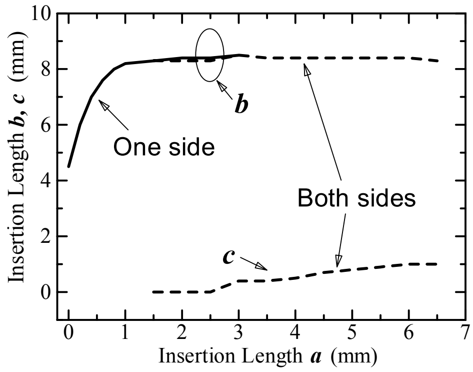

Figure 7: Insertion length for the optimum condition.

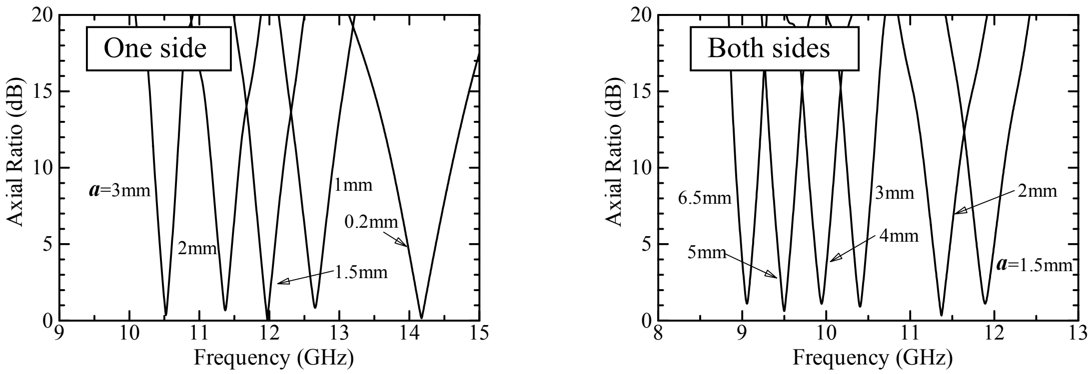

Figure 8: Frequency characteristics of axial ratios.

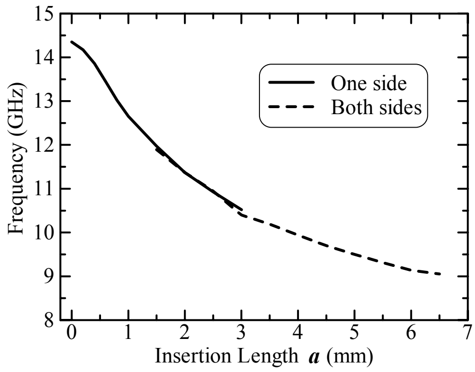

Figure 9: Operating frequency vs insertion length.

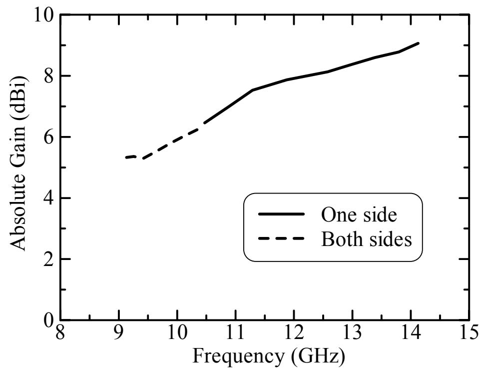

Figure 10: Operating frequency vs antenna gain.

4. Conclusion

In this paper, we proposed the circularly polarized wide 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. The obtained range of the frequency variation was 44 percent. This antenna can be used in applications requiring frequency diversity.

Acknowledgments

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References

[1] P. Bhartia and I. Bahl, “Frequency agile microstrip antennas,” Microwave Journal, vol.25, no.10, pp.67-70, 1982.
[2] T. Hukusako, A. Imahase and N. Mita, “Polarization characteristics of patch antenna using in-plane and weakly biased ferrite substrate,” IEEE Trans. Antennas propagat., vol.52, pp.325-327, 2004.
[3] Y. Suzuki, M. Haneishi, Y. Kimura, “A consideration on frequency controllable CP-MSA with variable reactance,” IEICE Gen. Conf, B-1-152, 2009 (in Japanese).
[4] S. Liu, M.-J. Lee, C. Jung, Li, G.-P., F. De Flaviis, “A frequency-reconfigurable circularly polarized patch antenna by integrating MEMS switches,” IEEE Antenna and Propag. International Symp., vol. 2A, pp.413- 416, 2005
[5] H. Manno, M. Katayama, K. Kitatani, Y. Okamura, “Circularly polarized frequency controllable microstrip patch antenna using partial dielectric filling,” Niigata Japan, 2007 International Symposium on Antennas and Propagation, 1A5-1, 2007.