Effect of Pin Radius on the Radiation Characteristics of Patch Antennas with Pin Arrays

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1.Introduction

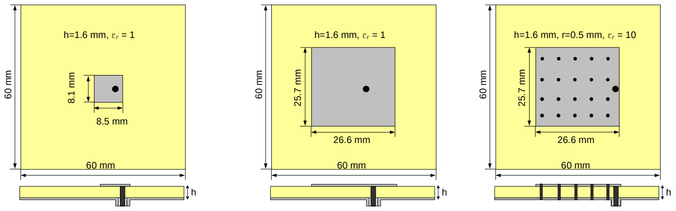
Microstrip patch antennas have become one of the most popular antennas since they have several merits such as low profile, light weight, easy integration with microwave integrated circuits, and low fabrication cost [1]. The high-index substrates which allow smaller footprint make microstrip antennas compatible with both active and passive devices for monolithic microwave integrated circuits (MMIC) and antenna applications [2]. To obtain high gain and wide bandwidth, electrically thick substrates need to be used. The increase in substrate thickness, however, tends to increase surface waves and radiation in horizontal directions so that substantial amount of power leaks into the substrate. This leads to enhance the mutual coupling between radiating elements, which results in the increase of both the sidelobe level and the cross-polarization level. Multiple-Input Multiple-Output (MIMO) systems of mobile terminals require miniaturized antennas and very low mutual coupling. Therefore, various techniques have been proposed to reduce the radiation in horizontal directions and the surface-wave.

These include grooving the dielectric [3], optimizing the antenna dimensions [4, 5], and covering the patch by additional dielectric layers [6]. In Ref. [7], an array of shorting pins between the patch and the ground has been proposed for the inductive currents in the pins and the capacitive polarization currents to cancel out against each other. In this paper, we investigate the effect of pin radius on the radiation characteristics of the patch antennas with pin arrays by experiment and by simulation using HFSS (High Frequency Structure Simulator). In section 2, design parameters used for three different types of patch antennas are given. Simulation and experimental results on the radiation characteristics are obtained and compared in section 3. Finally, section 4 concludes the paper.

2. Design of Patch Antennas with Pin Arrays

We have designed three types of patch antennas with a resonant frequency, f_0, of 5 GHz. Figs. 1. (a), (b), and (c) show the geometry of a conventional patch antenna fabricated on CER-10, a conventional patch antenna fabricated in air, and a patch antenna with pin arrays made on CER-10, respectively. CER-10 used in this paper has a dielectric constant, ε_r, of 10, and a loss tangent of 0.0035. The substrate for the patch antennas has a thickness, h, of 1.6 mm and a size of 60 x 60 mm^2. The patch antenna in air is used as a reference for performance comparison.

In order to create the patch antenna with an array of pins, the patch of conventional patch antenna in air has been divided into small rectangular cells. Then each cell can be considered as a parallel-plate capacitor. A pin is inserted into the cell center to interconnect the electrodes of the capacitor. Thus, it can be treated as an inductor also. Each cell with a pin becomes equivalent to an LC circuit. The radiation characteristics of the antenna could be obtained by solving the matrix of LC circuits.



(a) (b) (c)

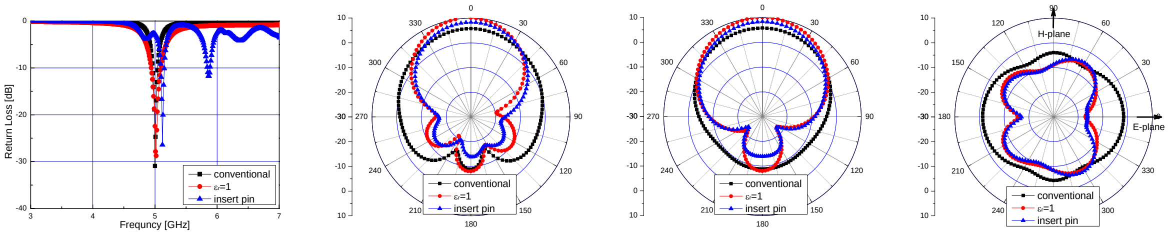
Fig. 1. Geometry of (a) a conventional patch antenna on CER-10, (b) a conventional patch antenna in air, and (c) a patch antenna with an array of pins on CER-10.

3. Radiation Characteristics of Patch Antennas with Pin Arrays

We have measured by simulation and experiment the radiation characteristics of the patch antennas designed in section 2. The comparison results are presented in section 3.1. The pin radius effect on the radiation characteristics of patch antennas with pin arrays is considered in section 3.2.

3.1 Radiation characteristics of patch antennas

The radiation characteristics of the three different patch antennas have been obtained by simulation using HFSS. Figure 2 shows the return loss, E-plane, H-plane, and horizontal plane radiation patterns. The results are summarized and compared in Table 1.



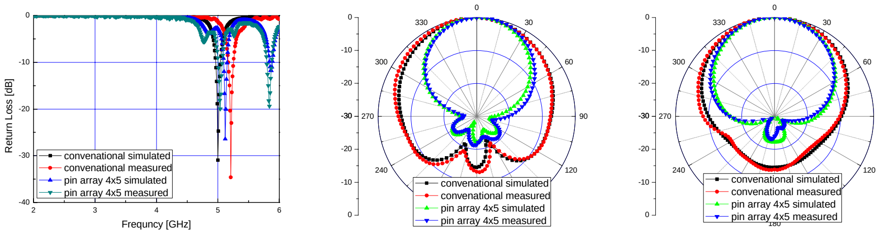
(a) (b) (c) (d)

Fig. 2. Simulation results on (a) return loss, (b) E-plane radiation pattern, (c) H-plane radiation pattern, and (d) horizontal plane radiation pattern for a conventional patch antenna on CER-10, an patch antenna in air, and a patch antenna with an array of 4x5 pins on CER-10.

Table 1. Performance comparison between three types of patch antennas.

	Substrate	Resonant Freq. (GHz)	Return loss (dB)	Broadside Radiation (dBi)	Back Radiation (dBi)	Horizontal Radiation (dBi)			
						0˚	90˚	180˚	270˚
Conventional	CER-10	5.00	-30.94	5.72	-8.77	-1.59	-4.02	-1.36	-4.33
	Air	5.02	-28.75	10	-8.01	-17.08	-9.01	-15.78	-8.39
Pin array	CER-10	5.12	-26.42	8.29	-13.89	-16.24	-8.71	-17.05	-8.31

For the case of conventional patch antennas, Table 1 shows that the broadside radiation from the patch antenna with larger dielectric constant, 5.72 dBi, is less than that from the antenna with smaller one, 10 dBi. As expected, this is due to the fact that larger dielectric constant generates more surface wave and radiation in horizontal directions. The patch antenna with an array of pins shows 2.57 dB gain improvement in broadside radiation power and about 5.12 dB improvement in back radiation over the conventional patch antenna on CER-10. Furthermore, the patch antenna with an array of pins shows the dramatic suppression of surface waves in Table 1 and Fig. 2(d). The radiation suppression in horizontal directions are more than 10 dB and 4 dB on E- and H-planes, respectively. The directivity is much improved since the half-power beamwidth in both E-plane and H-plane is greatly reduced.

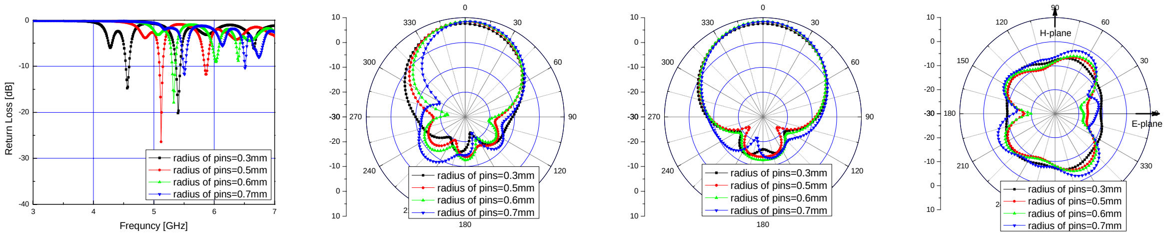


(a) (b) (c)

Fig. 3. Simulation and experimental results on (a) return loss, (b) E-plane, and (c) H-plane radiation pattern of both the conventional patch antenna and the patch antenna with an array of 4x5 pins on CER-10.

Simulation and experimental results of the conventional patch antenna and the patch antenna with an array of pins are compared in terms of the return loss, E-plane, and H-plane normalization radiation pattern as shown in Fig. 3. The figure shows in good agreement between the simulation and experimental results.

3.2 Effect of pin radius on radiation characteristics of patch antennas with 4x5 pin arrays



(a) (b) (c) (d)

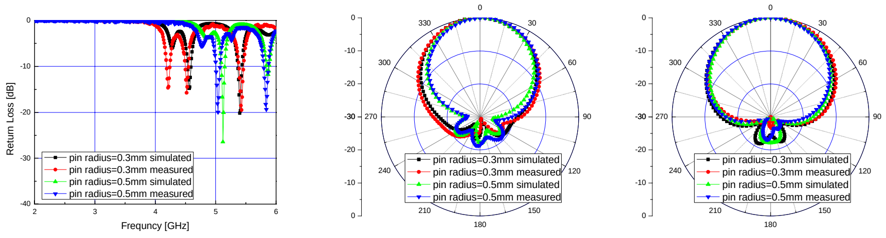
Fig. 4. Simulation results on (a) return loss, (b) E-plane, (c) H-plane, and (d) horizontal plane radiation pattern for the patch antenna with an array of pins for different pin radii.

The effect of pin radius on the radiation characteristics of the patch antenna with an array of pins has been investigated for different pin radii. Simulation results on the return loss, E-plane, H-plane, and horizontal plane radiation pattern are shown in Fig. 4. The results are summarized in Table 2. Increase in the pin radius causes the resonant frequency to increase and the radiation intensity on the horizontal plane to keep decreasing until it reaches 0.6 mm. For the case of 0.7 mm, the radiation in horizontal directions increases again. By careful observation of the data, we might say that there is an optimum pin radius to obtain the maximum suppression effect of the radiation in horizontal directions and the maximum directivity. In this work, it is around 0.6 mm.

Table 2. Simulation results of the patch antenna with an array of 4x5 pins for different pin radii.

Pin radius (mm)	Resonant Freq. (GHz)	Return loss (dB)	Broadside Radiation (dBi)	Back Radiation (dBi)	Horizontal Radiation (dBi)			
					0˚	90˚	180˚	270˚
0.3	4.56	-14.77	7.55	-16.87	-10.86	-7.81	-9.95	-7.29
0.5	5.12	-26.42	8.29	-13.89	-16.24	-8.71	-17.05	-8.31
0.6	5.33	-17.87	8.47	-12.63	-17.97	-8.35	-19.97	-8.28
0.7	5.51	-11.74	8.38	-14.52	-12.52	-6.50	-12.53	-7.53

Simulation and experimental results of the radiation characteristics for different pin radii are compared in terms of the return loss, E-plane, and H-plane normalization radiation pattern, as shown in Fig. 5. The figure shows in excellent agreement between the simulation and experimental results.



(a) (b) (c)

Fig. 5. Simulation and experimental results on (a) return loss, (b) E-plane, and (c) H-plane radiation pattern of the patch antenna with an array of 4x5 pins for pin radii of 0.3 mm and 0.5 mm.

4.Conclusion

In conclusion, the radiation characteristics of a patch antenna with an array of 4x5 pins have been investigated against the conventional patch antennas by both simulation and experiment in this paper. The effect of pin radius on the antenna performance also has been studied. The pins greatly suppress the radiation in horizontal directions leading to the reduction of mutual coupling. The radiation suppression in horizontal directions are measred to be more than 10 dB and 4 dB on E- and H-planes, respectively. Increase in pin radius causes the resonant frequency to increase and the radiation intensity on the horizontal plane to keep decreasing until it reaches 0.6 mm. The optimum pin radius to obtain the maximum suppression effect of radiation in horizontal directions and the maximum directivity has been observed to be around 0.6 mm in this work.

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