Effect of Substrate Thickness on the Radiation Characteristics of Inductor-loaded Patch Antenna

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1. Introduction

Microstrip patch antennas have many merits such as small size, light weight, low profile, and low cost [1]. Major disadvantages of microstrip patch antennas are their low efficiency and very narrow bandwidth. The increase of substrate thickness could improve the efficiency and bandwidth [2]. However, as the substrate thickness increases, surface waves increase which usually are not desirable [3]. The strong radiation along the horizontal plane is introduced by the polarization currents in the dielectric substrate underneath the patch. The technique for reducing the radiation by compensating the effect of the substrate using the insertion of a pin array between the patch and the ground has been presented in Ref. [4]. The inductive currents along the pins cancel out the polarization currents. The antenna using this technique behaves almost like being in the air.

In this paper, we investigate the effect of substrate thickness on the radiation characteristics of an inductor-loaded patch antenna for several substrate thicknesses by simulation using HFSS (High Frequency Structure Simulator) and experiment.

2. Geometry of the inductor-loaded patch antenna

The geometry of an inductor-loaded patch antenna is shown in Fig. 1. The substrate used for this study is Taconic CER-10 with the relative permittivity of 10 and the loss tangent of 0.0035. Antennas used in this paper are designed for the resonant frequency at 5.00 GHz (λ_0 = 60 mm) and fed by coaxial probe. The size of the substrate is 60 x 60 mm^2. The substrate thicknesses of 0.8 mm, 1.6 mm, and 3.2 mm are used to investigate the effect of substrate thickness on the performance of the antenna.

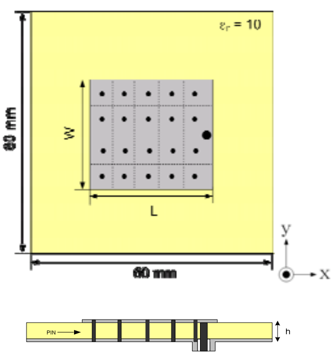

Figure 1: Geometry of the inductor-loaded patch antenna on top view and side view.

Table 1: The dimensions of inductor-loaded patch antennas for several substrate thicknesses.

Substrate thickness(h) [mm]	Patch length(L) [mm]	Patch width(W) [mm]	Pin radius [mm]
0.8	30.0	20.15	0.25
1.6	28.5	23.6	0.45
3.2	27.5	18.9	0.70

The pin array with 5 $\times$ 4 pins is inserted between the patch and the ground to compensate the effect of substrate, as shown in Fig. 1. The patch size of the inductor-loaded patch antenna is very close to that of the conventional patch antenna located in the air. Table 1 shows the dimensions of inductor-loaded patch antennas for several substrate thicknesses.

3. Effect of substrate thickness on radiation characteristics of antennas

Fig. 2 shows the simulation results of the return loss, E-plane radiation pattern, H-plane radiation pattern, and horizontal plane radiation pattern of inductor-loaded patch antennas for several substrate thicknesses. The increase of substrate thickness increases bandwidth, as shown in Fig. 2(a). Also, as substrate thickness increases, the boresight gain ($\theta = 0^{\circ}$) and the radiation gain in the horizontal plane (x-y plane) increase.

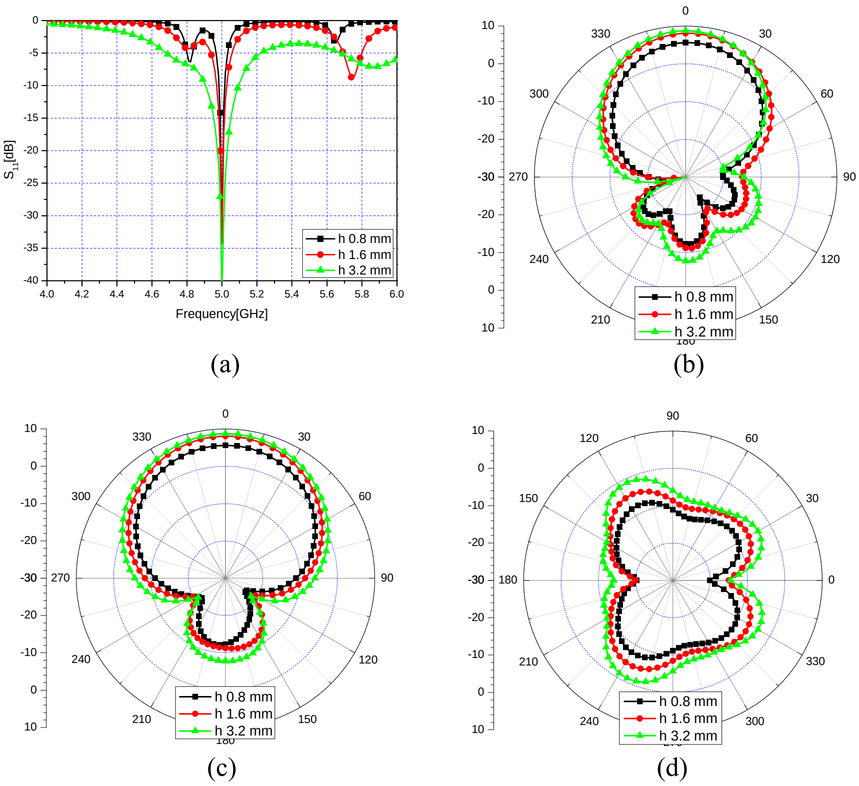

Figure 2: Simulation results of the characteristics of inductor-loaded patch antennas for several substrate thicknesses: (a) Return loss, (b) E-plane radiation pattern, (c) H-plane radiation pattern, and (d) Horizontal plane radiation pattern.

The simulation for the characteristics of conventional patch antennas for several substrate thicknesses has been performed to compare those of inductor-loaded patch antennas. Table 2 summarizes the simulation results of conventional and inductor-loaded patch antennas for several substrate thicknesses. The increase of substrate thickness increases the radiation in the horizontal plane. The suppression of the radiation gain along the length direction ($\Phi=0^{\circ}$, 180°) in horizontal plane of inductor-loaded patch antennas compared to those of conventional patch antennas is larger than about 15 dB, while that along the width direction ($\Phi=90^{\circ}$, 270°) is larger than about 3 dB. We think that the pin array on the patch suppresses the excitation of surface waves as well as the radiation along the horizontal plane.

The maximum boresight gain of the inductor-loaded patch antenna occurs in the case of substrate thickness of 3.2 mm, while that of the conventional patch antenna occurs in the case of substrate thickness of 1.6 mm. The difference of boresight gain between the conventional and inductor-loaded patch antenna increases as the substrate thickness increases. However, the half-power beamwidth of the conventional patch antenna increases rapidly, while that of the inductor-loaded patch antenna is about the same as the substrate thickness increases. The -10 dB frequency bandwidth of the inductor-loaded patch antenna is about 20% smaller than that of the conventional patch antenna.

Table 2: The simulation results.

Antenna type	Substrate Thickness [mm]	-10 dB Bandwidth [%]	Boresight Gain [dBi]	Half-power Beamwidth [˚]	Radiation gain in horizontal direction(Φ) [dBi]			
					0˚	90˚	180˚	270˚
Conventional	0.8	0.8	4.985	86	-2.95	-6.07	-3.11	-5.63
	1.6	1.6	5.840	96	-0.96	-4.51	-1.75	-4.61
	3.2	4.8	5.070	157	0.51	-3.99	1.47	-2.85
Pin arrays	0.8	0.7	5.590	49	-20.09	-11.11	-20.32	-11.16
	1.6	1.3	8.057	56	-15.04	-8.65	-20.05	-8.43
	3.2	3.8	8.709	53	-14.56	-6.00	-14.13	-5.71

4. Experiment results

We have fabricated conventional and inductor-loaded patch antennas for several substrate thicknesses. The radiation patterns are measured in an in-house anechoic chamber. Fig. 3 shows the return loss, E-plane radiation pattern, H-plane radiation pattern, and horizontal plane radiation pattern of inductor-loaded patch antennas for several substrate thicknesses. Table 3 summarizes the experiment results of conventional and inductor-loaded patch antennas for several substrate thicknesses. The experiment results show good agreement with the simulation results.

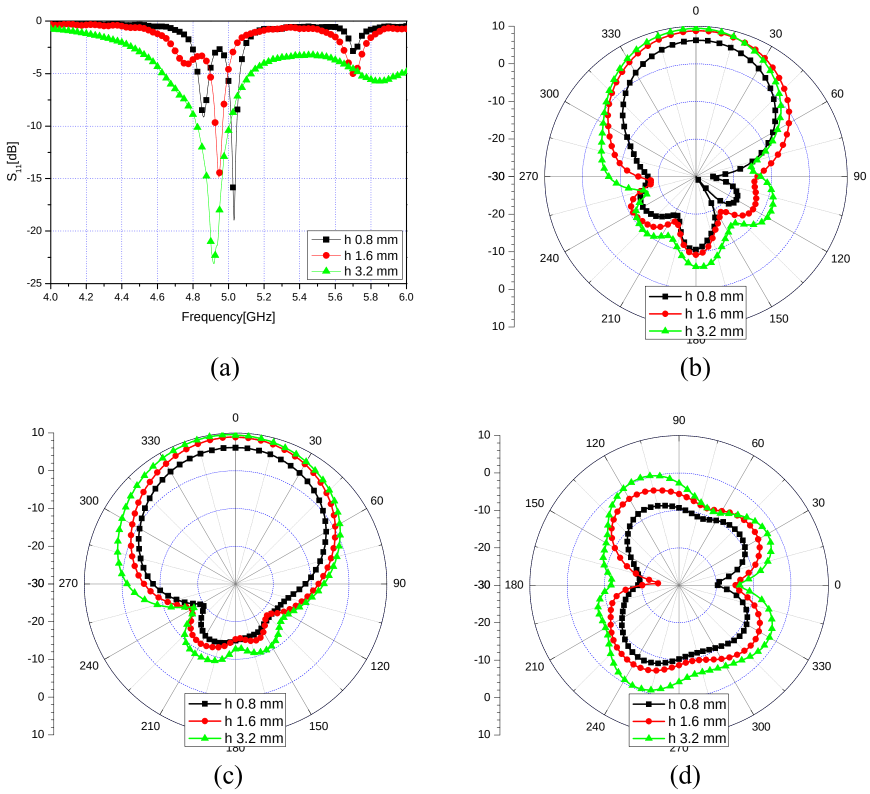

Figure 3: Experiment results of the characteristics of the inductor-loaded patch antenna for several substrate thicknesses: (a) Return loss, (b) E-plane radiation pattern, (c) H-plane radiation pattern, and (d) Horizontal plane radiation pattern.

Table 3: The experiment results.

Antenna type	Thickness [mm]	-10 dB Bandwidth [%]	Boresight Gain [dBi]	Half-power Beamwidth [˚]	Radiation gain in horizontal direction(Φ) [dBi]			
					0˚	90˚	180˚	270˚
Conventional	0.8	0.9	5.977	90	-2.81	-5.11	-2.09	-3.92
	1.6	1.6	6.797	104	-0.93	-3.34	-0.17	-1.85
	3.2	5.8	5.130	144	0.57	-2.06	3.17	0.68
Pin arrays	0.8	0.6	6.221	53	-19.65	-9.35	-19.00	-10.26
	1.6	0.9	8.714	60	-14.83	-5.63	-20.15	-8.63
	3.2	3.7	9.363	55	-13.72	-2.77	-11.76	-4.19

5. Conclusion

This paper has investigated the effect of substrate thickness on the radiation characteristics of an inductor-loaded patch antenna. The strong radiation along the horizontal plane is introduced by the polarization currents in the dielectric substrate underneath the patch. The increase of substrate thickness increases the radiation in the horizontal plane. The suppression of the radiation along the length direction in the horizontal plane of inductor-loaded patch antennas compared to those of conventional patch antennas is much larger than that along the width direction.

The half-power beamwidth of the conventional patch antenna increases rapidly, while that of the inductor-loaded patch antenna is about the same, and the difference of boresight gain between the conventional and inductor-loaded patch antenna increases as the substrate thickness increases. The radiation in the horizontal plane and the excitation of surface waves are suppressed by compensating the effect of the substrate using the insertion of a pin array between the patch and the ground.

Acknowledgments

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References

[1] Balanis, Constantine A., *Antenna Theory: Analysis and Design*, 2nd edition, John Wiley & Sons, Inc., 1997.

[2] R. Garg. P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, 2nd edition, Boston London, Artech House, 2000

[3] M. A. Khayat, J. T. Williams, D. R. Jackson, and S. A. Long, "Mutual coupling between reduced surface-wave microstrip antennas," *IEEE Trans. Antennas Propag.*, vol. 48, pp. 1581–1593, Oct. 2000.

[4] Marija M. Nikolic´, Antonije R. Djordjevic´, and Arye Nehorai, "Microstrip Antennas With Suppressed Radiation in Horizontal Directions and Reduced Coupling," *IEEE Trans. Antennas Propag.*, vol. 53, no. 11, pp. 3469-3476, Nov. 2005.