Radiation Characteristics of Rectangular Patch Antennas with an Array of Pins

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Abstract – The patch antennas with an array of pins (pin array patch antennas) with excellent radiation characteristics are investigated for various substrate thicknesses. The radiation in the horizontal plane of a pin array patch antenna is very small compared to that of a conventional patch antenna. And the increase of forward radiation and the decrease of backward radiation of a pin array patch antenna are obtained than those conventional one's. Also the half-power beamwidth of E-plane radiation pattern of a pin array patch antenna is narrower compared to that of the conventional so that the directivity is improved.

Key words – *microstrip patch antennas pin arrays*; *radiation characteristics*; *substrate thickness*

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1 Introduction

Microstrip patch antennas have become one of the most popular antennas because they have a lot of merits such as low-profile, light weight, easy integration with microwave integrated circuits, and low fabrication cost.

One of disadvantages of microstrip patch antennas is very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent. The simple method to increase the bandwidth is to increase the substrate thickness. As the substrate thickness increases, the generation of surface waves are increased. This surface waves generate strong radiation in horizontal directions. The mutual coupling between adjacent antenna elements in an array antenna occurs from the radiation in horizontal directions. Recently there is a paper using an array of pins interconnecting the patch and the ground to suppress the radiation in horizontal directions of patch antennas.

In this paper, we present the design method of patch antennas with an array of pins interconnecting the patch and the ground with maintaining resonant frequency. And we investigate the radiation characteristics of pin array patch antennas for various substrate thicknesses using High Frequency Structure Simulator(HFSS). In this study, the substrate used for the simulation of antenna is CER-10 with a relative dielectric constant of 10 and a loss tangent of 0.000 35. Also, the resonant frequency of antennas and the square substrate size investigated in this work are 5 GHz and 1 λ_0 (60 mm), respectively.

2 Design of a pin array patch antenna

Radiation characteristics of pin array patch antennas are very similar to those of conventional patch antennas with a substrate of a relative dielectric constant of 1. Fig. 1 shows the schematic diagram of a pin array patch antenna with a substrate of a relative dielectric constant of 1 for various substrate thicknesses. These antennas have an array of pins with 5×4 (5 period in length direction and 4 period in width direction) interconnecting the patch and the ground. Because the fringing field exits in the edge of a patch, the actual length of a patch is shorter than the electrical length. In the next section, we have investigated the characteristics of pin array patch antennas with several patch lengths for various substrate thicknesses.

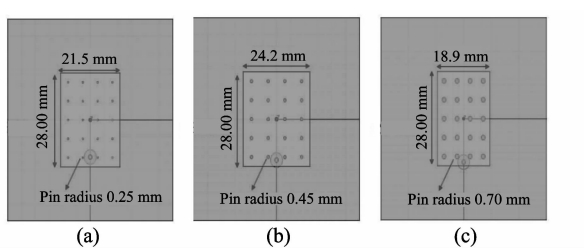

Fig. 1 The patch length, patch width, and radius of a pin of a patch antenna with an array of pins interconnecting the patch and the ground on: (a)substrate thickness of 0.8 mm, (b) substrate thickness of 1.6 mm,(c) substrate thickness of 3.2 mm

3 The patch length of a pin array patch antenna for various substrate thichnesses

3.1 The characteristics of a pin array patch antenna for various patch lengths with substrate thickness of 0.8 mm

We compared the characteristics of a pin array patch antenna for the patch length from 27.5 mm to 30.5 mm

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with a step of 0.5 mm with maintaining the resonant frequency of an antenna (fixing the pin radius of 0.25 mm and the area of a patch). Tab.1 shows the comparison of the radiation characteristics of a pin array patch antenna for various patch lengths. When the patch length is 30.0 mm, the antenna has the best radiation characteristics. All antennas have the forward radiation above 5.5 dBi. As the patch length increases, backward radiation increases because the width of a patch decreases. The radiation in horizontal direction of 0° and 180° and of 90° and 270° is suppressed maximally for the patch length of 30.0 mm.

Tab.1 The characteristics of a pin array patch antenna with the substrate thickness of 0.8 mm for various patch lengths

Patch length (mm)	Resonant frequeny (GHz)	S_{11} (dB)	Forward radiatin (dBi)	Backwad radiation (dBi)	Radiation in horizontal directions(dBi)			
					0°	90°	180°	270°
28.50	5.0	-33.81	5.665	-14.080	-17.19	-10.97	-22.00	-10.59
29.00	5.0	-30.71	5.661	-13.962	-17.88	-10.71	-22.77	-10.50
29.50	5.0	-29.27	5.559	-13.583	-19.31	-10.71	-22.54	-10.69
30.00	5.0	-25.76	5.581	-12.866	-20.07	-11.17	-21.86	-11.18
30.50	5.0	-22.68	5.513	-12.292	-21.93	-11.08	-19.78	-11.26

3.2 The characteristics of a pin array patch antenna for various patch lengths with substrate thickness of 1.6 mm

We compared the characteristics of a pin array patch antenna for the patch length from 28.0 mm to 30.0 mm with a step of 0.5mm with maintaining the resonant frequency of an antenna (fixing the pin radius of 0.45 mm and the area of a patch). Tab.2 shows the comparison of the radiation characteristics of a pin array patch antenna for various patch lengths. When the patch length is 28.5 mm, the antenna has the best radiation characteristics.

Tab.2 The characteristics of a pin array patch antenna with the substrate thickness of 1.6 mm for various patch lengths

Patch length (mm)	Resonant frequeny (GHz)	S_{11} (dB)	Forward radiatin (dBi)	Backwad radiation (dBi)	Radiation in horizontal directions(dBi)			
					0°	90°	180°	270°
28.00	5.00	-28.62	7.985	-12.314	-14.75	-8.44	-19.76	-8.50
28.50	5.00	-34.17	8.057	-11.240	-15.04	-8.65	-20.05	-8.43
29.00	5.00	-33.51	8.068	-10.485	-15.50	-8.39	-18.51	-8.51
29.50	5.00	-32.66	7.992	-10.226	-15.68	-8.43	-16.33	-8.51
30.00	5.00	-27.99	7.948	-9.373	-15.19	-8.41	-14.56	-8.44

All antennas have the forward radiation above 7.9 dBi. As the patch length increases, backward radiation increases because the width of a patch decreases. The radiation in horizontal direction of 0° and 180° and of 90° and 270° is suppressed maximally for the patch length of 28.5 mm.

3.3 The characteristics of a pin array patch antenna for various patch lengths with substrate thickness of 3.2 mm

We compared the characteristics of a pin array patch antenna for the patch length from 27.0 mm to 29.0 mm with a step of 0.5 mm with maintaining the resonant frequency of an antenna (fixing the pin radius of 0.70 mm and the area of a patch). Tab.3 shows the comparison of the radiation characteristics of a pin array patch antenna for various patch lengths. When the patch length is 27.5 mm, the antenna has the best radiation characteristics.

Tab.3 The characteristics of a pin array patch antenna with the substrate thickness of 3.2 mm for various patch lengths

Patch length (mm)	Resonant frequeny (GHz)	S_{11} (dB)	Forward radiatin (dBi)	Backwad radiation (dBi)	Radiation in horizontal directions(dBi)			
					0°	90°	180°	270°
27.00	5.00	-36.68	8.687	-8.733	-13.93	-5.90	-14.16	-5.46
27.50	5.00	-39.69	8.633	-7.975	-13.24	-5.93	-15.24	-5.71
28.00	5.00	-29.83	8.745	-7.171	-12.73	-5.89	-13.38	-5.94
28.50	5.00	-21.15	8.615	-6.823	-12.57	-6.08	-12.20	-5.86
29.00	5.00	-16.13	8.532	-6.153	-10.80	-6.08	-11.01	-6.02

All antennas have the forward radiation above 8.5 dBi. As the patch length increases, backward radiation increases because the width of a patch decreases. The radiation in horizontal direction of 0° and 180° and of 90° and 270° is suppressed maximally for the patch length of 27.5 mm.

4 Comparison of the radiation characteristics of a conventional patch antenna and a pin array patch antenna for various substrate thicknesses

Pin array patch antennas with excellent radiation characteristics are designed for various substrate thicknesses. Tab.4 shows the comparison of the radiation characteristics of a conventional patch antenna and a pin array patch antenna for various substrate thicknesses.

The radiation in the horizontal plane of a pin array patch antenna is very small compared to that of a conventional patch antenna. The increase of forward radiation and the decrease of backward radiation of a pin array patch antenna are obtained compared to those of a conventional patch antenna. Specially, pin array patch anten-

Tab. 4 The comparison of the radiation characteristics of a conventional patch antenna and a pin array patch antenna for various substrate thicknesses

Thickness (mm)	Type	resonant frequency (GHz)	S_{11} (dB)	Forward radiation (dBi)	Backward radiation (dBi)	radiation in horizontal directions (dBi)			
						0°	90°	180°	270°
0.8	conventional	5.00	-26.32	4.973	-9.817	-3.13	-6.02	-2.85	-5.96
	pin array	5.00	-25.76	5.581	-12.866	-20.07	-11.17	-21.86	-11.18
1.6	conventional	5.00	-29.27	5.838	-8.574	-1.56	-4.37	-1.23	-4.03
	pin array	5.00	-34.17	8.057	-11.240	-15.04	-8.65	-20.05	-8.43
3.2	conventional	5.00	-40.28	4.816	-7.577	0.17	-2.75	1.51	-2.70
	pin array	5.00	-39.69	8.633	-7.975	-13.24	-5.93	-15.24	-5.71

nas suppress considerably the radiation in the horizontal directions which causes mutual coupling between adjacent antenna elements of an array antenna.

Fig. 2 shows S_{11} spectrum, E-plane, H-plane, and horizontal plane radiation pattern of pin array patch antennas for various substrate thicknesses.

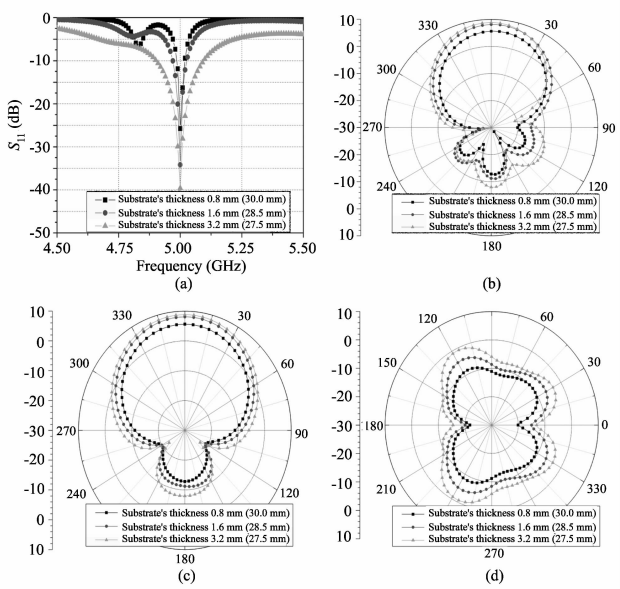

Fig. 2 Radiation characteristics of a pin array patch antenna for several substrate thicknesses: (a) S_{11} spectrum, (b) E-plane radiation pattern, (c) H-plane radiation pattern,, (d) Horizontal plane radiation pattern

Tab. 5 Comparison of the radiation characteristics of a pin array patch antenna for several substrate thicknesses

Thickness (mm)	Bandwidth (%)	Forward radiation (dBi)	Backward radiation (dBi)	Radiation in horizontal directions(dBi)			
				0°	90°	180°	270°
0.8	0.7	5.581	-12.866	-20.07	-11.17	-21.86	-11.18
1.6	1.6	8.057	-11.240	-15.04	-8.65	-20.05	-8.43
3.2	3.2	8.633	-7.975	-13.24	-5.93	-15.24	-5.71

As the substrate thickness increases, the radiation intensities of E-plane, H-plane and horizontal plane increase. Tab. 5 shows the radiation characteristics of pinarray patch antennas for various substrate thicknesses. The bandwidth is 0.7%, 1.6%, and 3.2% for the substrate thickness of 0.8 mm, 1.6 mm, and 3.2 mm, respectively. As the substrate thickness increases, the forward radiation, the backward radiation, and the radiation in horizontal directions increase.

5 Conclusions

The radiation characteristics of pin array patch antennas with constant resonant frequency forvarious substrate thicknesses are investigated versus the patch length. The patch length for excellent radiation characteristics is 30.0 mm, 28.5 mm, and 27.5 mm for the substrate thickness of 0.8 mm, 1.6 mm, and 3.2 mm, respectively.

As the substrate thickness increases, the forward radiation, the backward radiation, and the radiation in horizontal directions of a pin array patch antenna increase. The radiation in the horizontal plane of a pin array patch antenna is very small compared to that of a conventional patch antenna. The increase of forward radiation and the decrease of backward radiation of a pin array patch antenna are obtained compared to those of a conventional patch antenna. The half-power beamwidth of E-plane radiation pattern of a pin array patch antenna is narrow compared to that of a conventional patch antenna so that the directivity is improved.

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