Effect of Substrate Size on the Mutual Coupling of a Pair of Microstrip Patch Antennas Positioned along the E-plane

Young-Min Yoon, Tae-Young Kim, Hwan-Mo Koo, and #Boo-Gyoun Kim
School of Electronic Engineering, Soongsil University
511 Sangdo-dong, Dongjak-gu, Seoul 156-743, Korea
Tel. +82-2-820-0635, Fax. +82-2-813-1596
E-mail: bgkim@e.ssu.ac.kr

Abstract

The mutual coupling of microstrip patch antennas positioned along the E-plane including the effect of edge diffraction is investigated by the experiment and full wave simulation. The optimum substrate size with the minimum mutual coupling is easily calculated by the image method. The optimum substrate sizes calculated by the image method are in good agreement with the results obtained by the full wave simulation and experiment.

Keywords : Mutual coupling, Microstrip patch antennas, Edge effect, Surface wave, Image method

1. Introduction

Mutual coupling between adjacent antenna elements significantly affects the performance of antenna arrays such as side lobe level control. To reduce the mutual coupling there have been many different kinds of methods suggested. The electromagnetic band gap (EBG) structures have been used to reduce the mutual coupling between two microstrip patch antennas [1-3]. The mutual coupling of microstrip antennas integrated with EBG structures was parametrically investigated, including both the E- and H-coupling directions, different substrate thickness, and various dielectric constants. However, the effect of edge diffractions on the mutual coupling was not considered in that study [1]. G. Mazzarella and G. Panariello showed that the edge diffracted field due to each slot in slot arrays is practically equal to the field of a mirror image of such slot [4]. L. Josefsson calculated the mutual coupling between rectangular waveguide elements in a finite ground plane including the effect of edge diffraction [5].

We investigate the mutual coupling of microstrip patch antennas positioned along the E-plane on a finite grounded dielectric substrate including the effect of edge diffraction by the experiment and simulation using HFSS. In section 2, a simple formula for the distance between the antenna center and the substrate edge on the H-plane with the minimum mutual coupling calculated by the image method is presented. And the simulation results on the mutual coupling of microstrip patch antennas with various substrate sizes are presented. In section 3, experimental results on the mutual coupling of microstrip patch antennas with various substrate sizes are presented and compared with the results of the simulation and image method. Finally, section 4 concludes this paper.

2. The Image Method and Simulation Results

Fig. 1 shows the schematic diagram of a pair of microstrip patch antennas positioned along the E-plane. The quantity d represents the distance between the antenna centers. The distances between the antenna center and the substrate edges on the E-plane and H-plane are represented by the quantities d_E and d_H, respectively. The substrate used in this section for the simulation is a Taconic CER-10 with a dielectric constant of 10 and loss tangent of 0.0035. The patch sizes with the resonant frequency of 5 GHz (λ_0 =60 mm) are 8.5 mm × 8.1 mm and 7.2 mm × 6 mm for the substrate thickness, h, of 1.6 mm and 3.2 mm, respectively. The quantity λ_0 represents the wavelength in free space.

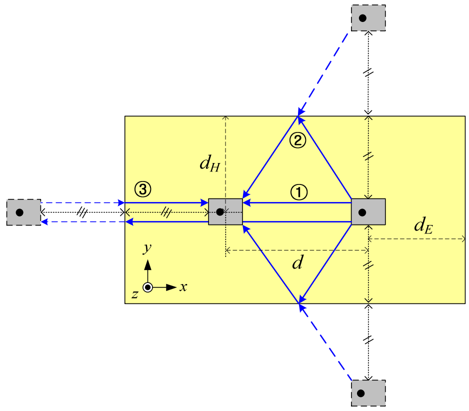


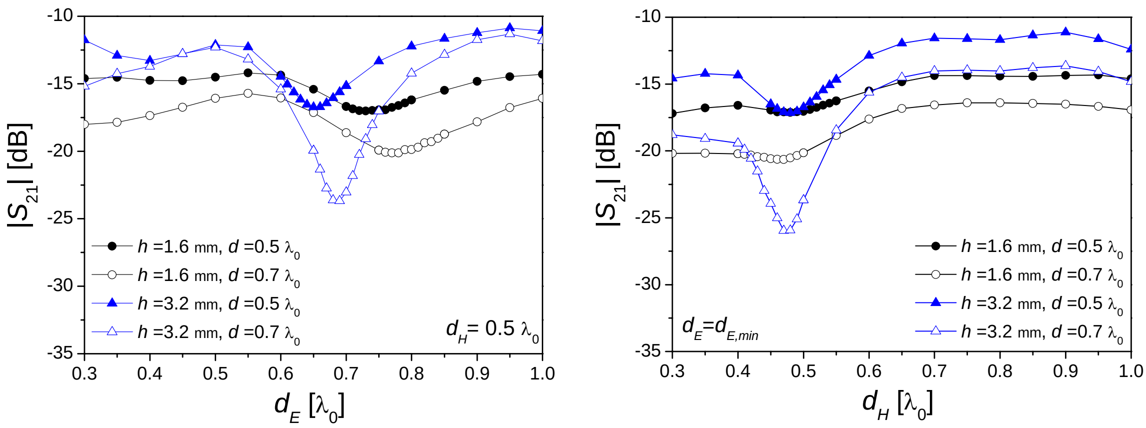
Fig. 1. Schematic diagram of a pair of patch antennas positioned along the E-plane.

The mutual coupling of microstrip patch antennas positioned along the E-plane is mainly determined by the following three components of surface waves; ① the surface wave which is directly propagated between two patch antennas, ② the surface wave that can be occurred by the diffraction from the substrate edges on the H-plane, and ③ the surface wave that can be occurred by the diffraction from the substrate edges on the E-plane. The diffraction from the substrate edges of the surface wave is an important factor to modify the mutual coupling of microstrip patch antennas.

In order to investigate the effect of substrate size on the mutual coupling of 2-element antenna array positioned along the E-plane, the image method is considered as shown in Fig. 1. The distances between the antenna center and the substrate edge on the E-plane and the H-plane with the minimum mutual coupling are represented by the quantity $d_{E,min}$ and $d_{H,min}$, respectively. The quantity $d_{E,min}$ calculated by the image method is the d_E at which the phase difference between the direct surface wave component ① and the diffracted surface wave component ③ from the substrate edges on the E-plane is π. The quantity $d_{H,min}$ calculated by the image method is given by the simple formula (1).

$$d_{H,\min} = \frac{\lambda_g}{2}\sqrt{\frac{d}{\lambda_g} + \frac{1}{4}} \tag{1}$$

The quantity λ_g represents the guided wavelength in a grounded dielectric substrate. The effective dielectric constants of the grounded CER-10 substrate for h =1.6 mm and 3.2 mm are 1.03 and 1.23, respectively.



(a) (b)

Fig. 2. The simulated mutual coupling between a pair of patch antennas for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0 with the substrate thickness of 1.6 mm and 3.2 mm at 5 GHz versus the distance between the antenna center and the substrate edge on (a) the E-plane and (b) the H-plane.

Fig. 2(a) shows the simulated mutual coupling of patch antennas for the quantity d of 0.5 λ_0 and 0.7 λ_0 and the substrate thickness of 1.6 mm and 3.2 mm, versus the quantity d_E from 0.3 λ_0 to 1.0 λ_0 with a step of 0.05 λ_0. In the vicinity of $d_{E,min}$, simulations have been performed in detail with a step of 0.01 λ_0. The quantity d_H was kept at 0.5 λ_0 in all cases. In Fig. 2(a) the mutual coupling variations in the case of d = 0.5 λ_0 and d = 0.7 λ_0 are about 6 dB (3 dB) and 12 dB (4 dB) for the substrate thickness of 3.2 mm (1.6 mm). The variation of the mutual coupling increases with the substrate thickness due to the increase of surface waves.

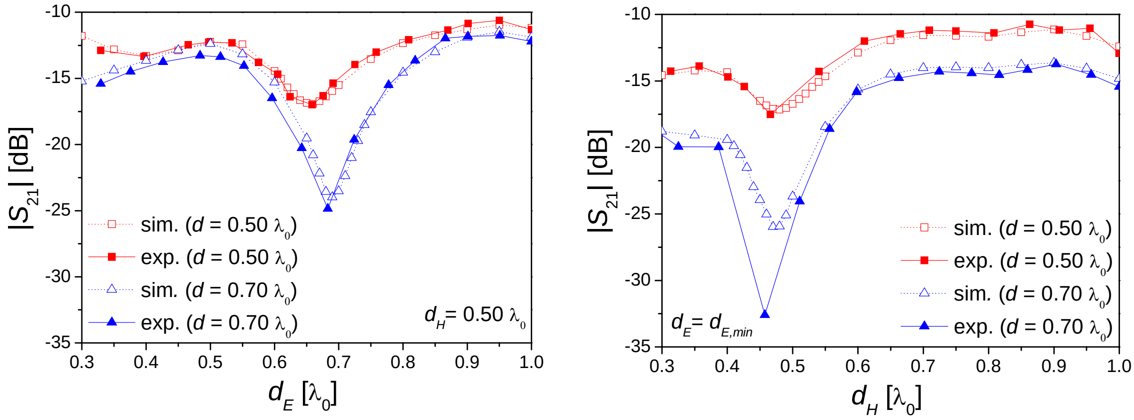
Fig. 2(b) shows the simulated mutual coupling of patch antennas for the quantity d of 0.5 λ_0 and 0.7 λ_0 and the substrate thickness of 1.6 mm and 3.2 mm, versus the quantity d_H from 0.3 λ_0 to 1.0 λ_0 with a step of 0.05 λ_0. In the vicinity of $d_{H,min}$, simulations have been performed in detail with a step of 0.01 λ_0. In each case the quantity d_E was fixed at $d_{E,min}$. The $d_{E,min}$ and $d_{H,min}$ obtained by the simulation and image method for the quantity d of 0.5 λ_0 and 0.7 λ_0 and the substrate thickness of 1.6 mm and 3.2 mm are summarized in Table 1. The results calculated by the image method are in good agreement with the simulation results.

Table 1. Comparison of the $d_{E,min}$ and $d_{H,min}$ obtained by the simulation and image method for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0 with the substrate thickness of 1.6mm and 3.2 mm

h [mm]	d [λ_0]	$d_{E,min}$ [λ_0] at d_H = 0.5 λ_0			$d_{H,min}$ [λ_0] at d_E = $d_{E,min}$		
		simulated	Image method	difference [%]	simulated	Image method	difference [%]
1.6	0.5	0.73	0.74	1.4	0.48	0.43	10.4
	0.7	0.77	0.74	3.9	0.47	0.48	2.1
3.2	0.5	0.65	0.68	4.6	0.48	0.40	16.7
	0.7	0.69	0.68	1.4	0.47	0.46	2.1

3. Experimental Results

Since the effect of the diffracted field of surface wave from the substrate edges on the mutual coupling of microstrip patch antennas with the substrate thickness of 3.2 mm is larger than that with the substrate thickness of 1.6 mm, two patch antennas are fabricated on a Taconic CER-10 substrate with the thickness of 3.2 mm.



(a) (b)

Fig. 3. The simulated and measured mutual coupling between a pair of patch antennas for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0 with the substrate thickness of 3.2 mm at 5 GHz versus the distance between the antenna center and the substrate edge on (a) the E-plane and (b) the H-plane.

Fig. 3(a) shows the simulated and measured mutual coupling of microstrip patch antennas for the quantity d of 0.5 λ_0 and 0.7 λ_0, versus the quantity d_E with a fixed d_H of 0.5 λ_0. The measured results are in good agreement with the simulation results. In the case of d = 0.5 λ_0 (d = 0.7 λ_0), the $d_{E,min}$ obtained by the simulation and measurement are 0.65 λ_0 (0.69 λ_0) and 0.66 λ_0 (0.68 λ_0), respectively.

Fig. 3(b) shows the simulated and measured mutual coupling of microstrip patch antennas for the quantity d of 0.5 λ_0 and 0.7 λ_0, versus the quantity d_H with a fixed d_E of $d_{E,min}$ in each case. In the case of d = 0.5 λ_0 (d = 0.7 λ_0), the $d_{H,min}$ obtained by the simulation and measurement are 0.48 λ_0 (0.47 λ_0) and 0.47 λ_0 (0.46 λ_0), respectively. The results are summarized in Table 2. The measured results are in good agreement with the simulated results.

Table 2. Comparison of the $d_{E,min}$ and $d_{H,min}$ obtained by the experiment and simulation for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0 with the substrate thickness of 3.2 mm

h [mm]	d [λ_0]	$d_{E,min}$ [λ_0] at d_H = 0.5 λ_0		$d_{H,min}$ [λ_0] at d_E = $d_{E,min}$	
		simulated	measured	simulated	measured
3.2	0.5	0.65	0.66	0.48	0.47
	0.7	0.69	0.68	0.47	0.46

4. Conclusion

The mutual coupling of microstrip patch antennas on a finite grounded dielectric substrate is influenced by the diffracted fields of surface wave from the edges of a substrate. The optimum substrate size with the minimum mutual coupling is easily calculated by the image method. The optimum substrate sizes calculated by the image method are in good agreement with the results obtained by the full wave simulation and experiment.

The measured minimum mutual coupling is -17.51 dB and -32.59 dB and the measured maximum mutual coupling is -10.62 dB and -11.75 dB for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0, respectively, with the substrate thickness of 3.2 mm at 5 GHz. As a result, significant 6.89 dB and 20.84 dB mutual coupling reductions are achieved for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0, respectively.

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