Effect of Surface Wave Diffraction on the Mutual Coupling of 2-element Microstrip Patch Antennas Positioned along the H-plane

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Abstract

The effect of a finite substrate on the mutual coupling of a pair of microstrip patch antennas positioned along the H-plane is investigated for different substrate thicknesses and distances between antenna centers. The substrate size with the minimum mutual coupling is easily calculated by the image method. The optimum substrate sizes calculated by image method are in good agreement with the results obtained by the full wave simulation and measurement.

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

1. Introduction

The surface waves in most practical microstrip patch antennas on a grounded dielectric substrate would increase the mutual coupling between antenna elements, which may reduce the scan range and cause the scan blindness in phased array antennas [1]. Various methods have been developed to suppress the mutual coupling in array design, such as electromagnetic band-gap (EBG) structures [2-4] and defected ground structures (DGS) [5]. Since surface waves propagate along the E-plane direction, the mutual coupling between antennas positioned along the E-plane is stronger on a high permittivity substrate than that on a low permittivity substrate. In contrast the mutual coupling between antennas positioned along the H-plane is weaker on a high permittivity substrate than that on a low permittivity substrate. This is because the antennas on a low permittivity substrate have a larger patch size and their fringing fields couple to each other, resulting in a strong mutual coupling [4-5]. However, the diffracted surface wave from the substrate edges on the E-plane can increase the mutual coupling of patch antenna arrays positioned along the H-plane with a small patch size on a high permittivity substrate.

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

2. The Image Method

Fig. 1 shows the schematic diagram of a pair of microstrip patch antennas positioned along the H-plane. In Fig. 1 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 mutual coupling of microstrip patch antennas positioned along the H-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 E-plane, and ③ the surface wave that can be occurred by the diffraction from the nearest corner of the substrate. The diffracted surface wave from the substrate edges on the E-plane is an important factor to modify the mutual coupling of microstrip patch antennas positioned along the H-plane.

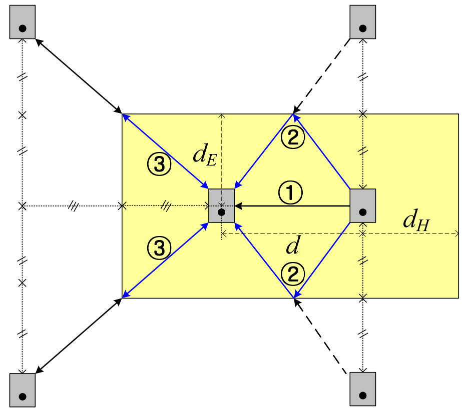


Fig. 1. Schematic diagram of a pair of patch antennas positioned along the H-plane

In order to investigate the effect of substrate size on the mutual coupling of 2-element antenna array positioned along the H-plane, the image method is considered as shown in Fig. 1. The distance 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 ② from the substrate edges on the E-plane is π. The $d_{E,min}$ calculated by the image method is given by the simple formula (1).

$$d_{E,\min} = \frac{\lambda_g}{2}\sqrt{\frac{d}{\lambda_g}+\frac{1}{4}} \qquad (1)$$

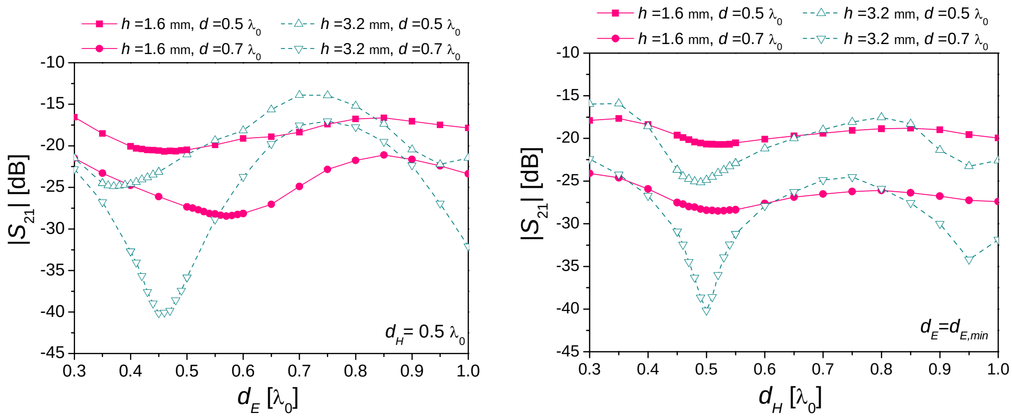
The quantity λ_g represents the guided wavelength in a grounded dielectric substrate.

The quantity $d_{H,min}$ calculated by the image method is the d_H at which the phase variation after one round trip of surface wave component ③ from the antenna center to the nearest corner of the substrate is π. The $d_{H,min}$ calculated by the image method is given by the formula (2).

$$d_{H,\min} = \sqrt{\frac{9}{16}\lambda_g^2 - d_E^2} \qquad (2)$$

3. Simulation and Measurement Results

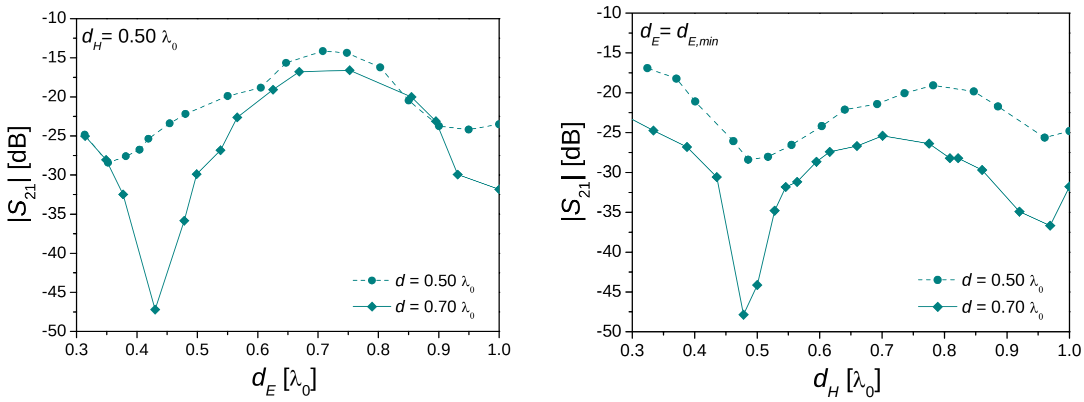
The mutual couplings of microstrip patch antennas positioned along the H-plane with various substrate sizes are simulated for the substrate thickness, *h*, of 1.6 mm and 3.2 mm. And two patch antennas are fabricated and measured only for a substrate thickness of 3.2 mm since the effect of the diffracted field of surface waves 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. The substrate used for the simulation and measurement is a Taconic CER-10 with a dielectric constant of 10 and a loss tangent of 0.0035. A high permittivity dielectric substrate is chosen to reduce the patch size, resulting in a weak direct mutual coupling between antenna elements due to the fringing field. The patch sizes with the resonant frequency of 5 GHz are 8.5 mm × 8.1 mm and 7.2 mm × 6 mm for the *h* of 1.6 mm and 3.2 mm, respectively. 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 λ_0 represents the wavelength in free space. The quantity d_H was kept at 0.5 λ_0 in all cases. In Fig. 2(a) the mutual coupling variations for the quantity d of 0.5 λ_0 and 0.7 λ_0 are about 11 dB (4 dB) and 23 dB (7 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 $d_{E,min}$. In Fig. 2 the maximum mutual coupling with various substrate sizes is about -16 dB and -14 dB for the substrate thickness of 1.6 mm and 3.2 mm, respectively.



(a) (b)

Fig. 3. The 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 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 fixed d_H of 0.5 λ_0. The measured results are in good agreement with the simulation results in Fig. 2(a). 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 0.37 λ_0 (0.35 λ_0) and 0.45 λ_0 (0.40 λ_0), respectively.

Fig. 3(b) shows the 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 0.50 λ_0 (0.49 λ_0) and 0.50 λ_0 (0.48 λ_0), respectively. The simulated and measured results are summarized and compared with image method results in Table 1. The results calculated by the image method are in good agreement with the simulation and measurement results.

Table 1. Comparison of the $d_{E,min}$ and $d_{H,min}$ obtained by the simulation, measurement, 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]			$d_{H,min}$ [λ_0]		
		simulation	measurement	Image method	simulation	measurement	Image method
1.6	0.5	0.46	-	0.43	0.52	-	0.58
	0.7	0.57	-	0.48	0.52	-	0.47
3.2	0.5	0.37	0.35	0.40	0.5	0.49	0.57
	0.7	0.45	0.40	0.46	0.5	0.48	0.51

4. Conclusion

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

The measured minimum mutual coupling is -28.41 dB and -47.86 dB and the measured maximum mutual coupling is -14.14 dB and -16.60 dB for the distances between the antenna centers of 0.5 λ_0 and 0.7 λ_0, respectively, using the fabricated microstrip patch antennas on a CER-10 substrate with the thickness of 3.2 mm at 5 GHz. As a result, significant 14.27 dB and 31.26 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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