Effect of the Effective Dielectric Constant on the Radiation Characteristics of a Microstrip Patch Antenna

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Abstract

The radiation characteristics of a microstrip patch antenna versus the grounded dielectric substrate size are mainly determined by the effective dielectric constant of a grounded dielectric substrate. Excellent agreement between the simulation and experimental results shows that the largest front-to-back ratio due to the large broadside gain and the minimum back lobe gain is obtained when the substrate size is 0.8 λ_0.

Keywords : Radiation Patterns, Edge Effect, Microstrip Patch Antenna, Effective Dielectric Constant, Surface Wave.

1. Introduction

Microstrip patch antennas have become one of the most popular antennas because they have many advantages such as low-profile, light weight, low fabrication cost, and easy integration with monolithic microwave integrated circuits (MMICs) [1]. However, high dielectric constant substrates tend to increase surface waves and radiation in horizontal directions. When the size of a grounded dielectric substrate is finite, the radiation pattern of a microstrip patch antenna is determined by the interference of directly radiated field from the patch and the diffracted field of surface waves from substrate edges.

A lot of research has been made to investigate the radiation characteristics of a patch antenna with a finite grounded dielectric substrate [2-5]. Recently, an efficient analysis of probe-fed microstrip antennas on arbitrarily-shaped, finite-sized ground plane and substrate was presented [5]. In this paper, the radiation characteristics of a microstrip patch antenna are investigated systematically for various sizes of a square grounded dielectric substrate with various dielectric constants by the simulation using HFSS and experiment.

2. Effect of the Effective Dielectric Constant on the Radiation Characteristics of a Microstrip Patch Antenna

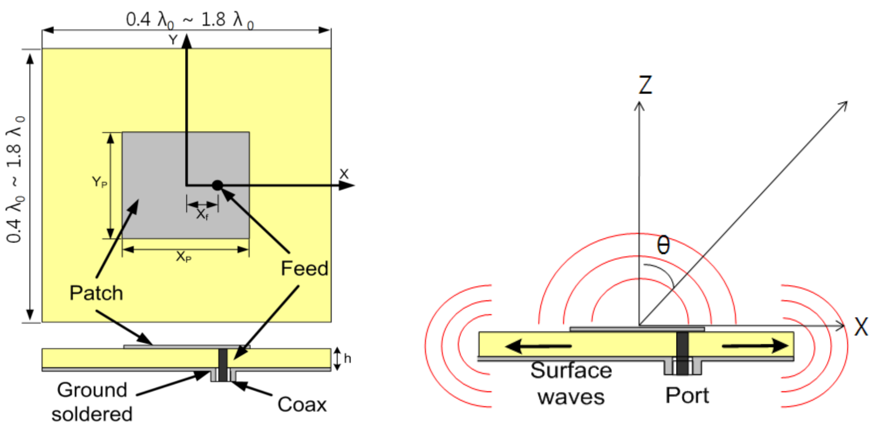
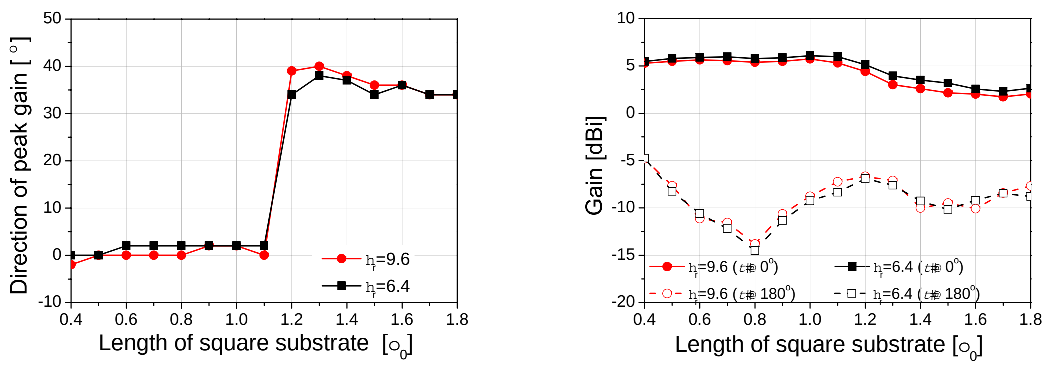


Fig. 1. (a) Geometry of a probe-fed microstrip patch antenna and (b) the schematic diagram of the E-plane radiation composed of the direct radiation from the patch and the diffraction of surface waves from substrate edges.

Fig. 1(a) shows the geometry of a probe-fed microstrip patch antenna. The offset of the feed point from the center of the patch in the x-direction and the substrate thickness are represented by the quantities x_f and h, respectively. The substrate is a Taconic CER-10 substrate with a dielectric constant, ε_r, of 9.6 and a loss tangent of 0.0035. The patch size with the resonant frequency of 5 GHz (λ_0=60 mm) is 8.7 mm × 8.2 mm and the probe-fed point, x_f, is 1.1 mm for h=1.58 mm. The quantity λ_0 represents the wavelength in free space. The effective dielectric constant, ε_{eff}, of the grounded dielectric substrate is 1.03.

Fig. 1(b) shows the schematic diagram of the E-plane radiation composed of the direct radiation from the patch and the diffraction of surface waves from substrate edges. The diffraction of surface waves from substrate edges is an important factor to modify the radiation pattern. The diffraction from the substrate edges radiates backwards as well as forwards. The radiation directly from the patch and the diffraction of surface waves from substrate edges interfere to form a series of multipath lobes and nulls at various angles.

To investigate the effect of the effective dielectric constant of a grounded dielectric substrate on the radiation characteristics of a microstrip patch antenna, the patch antenna with the resonant frequency of 5.4 GHz (λ_0=56 mm) is fabricated on the RF60A substrate with a thickness of 1.52 mm, a dielectric constant of 6.4, and a loss tangent of 0.0038. The patch size is 10.13 mm × 7.0 mm and the x_f is 1.1 mm. The effective dielectric constant of the RF60A with the substrate thickness of 1.52 mm at the resonant frequency of 5.4 GHz is the same as that of the CER-10 with the substrate thickness of 1.58 mm at the resonant frequency of 5 GHz.

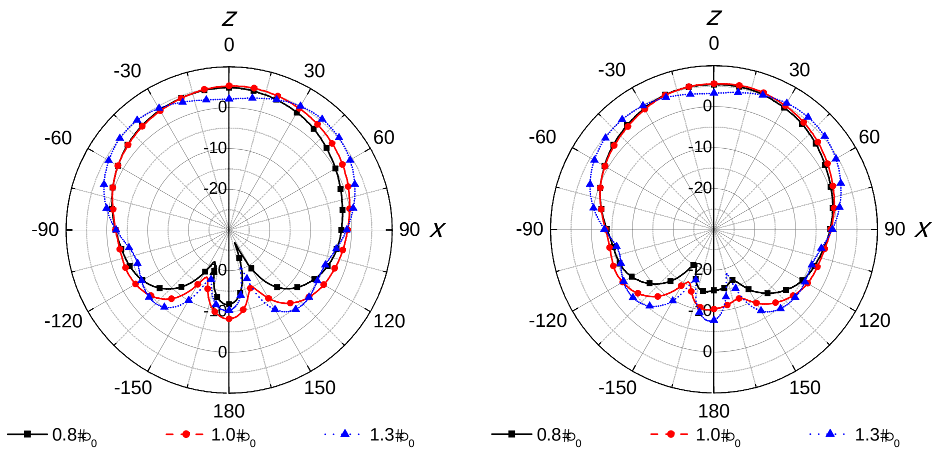


(a) (b)

Fig. 2. Simulation results of (a) the direction of peak gain, and (b) the broadside (θ=0°) gain and the back lobe gain (θ=180°) versus the substrate size with the dielectric constants of 9.6 and 6.4.

The radiation characteristics of patch antennas with various square substrate sizes from 0.4 λ_0 to 1.8 λ_0 with a step of 0.1 λ_0 are investigated by simulation. Fig. 2 (a) and (b) show the simulation results of the direction of peak gain, and the broadside (θ = 0°) and back lobe gains (θ = 180°) versus the substrate size for ε_r=9.6 and 6.4, respectively. The variations of the peak gain direction are 40° and 38° for ε_r=9.6 and 6.4, respectively, as shown in Fig. 2(a). Fig. 2 (b) shows the variations of the broadside gain (the back lobe gain) are 4.01 dB (9.01 dB) and 3.77 dB (9.78 dB) for ε_r=9.6 and 6.4, respectively. The back radiation of a microstrip patch antenna is mainly determined by the diffracted field of surface waves from the substrate edges. The front-to-back (F/B) ratio is defined by the ratio of the broadside gain to the back lobe gain. The simulation results show that the maximum F/B ratio due to the large broadside gain and the minimum back lobe gain is obtained for the substrate size of 0.8 λ_0 for both ε_r=9.6 and 6.4.

We choose the three different substrate sizes, which give the maximum F/B ratio, maximum broadside gain, and maximum direction of peak gain for the experiment of radiation characteristics of a patch antenna. The corresponding substrate sizes are 0.8 λ_0, 1.0 λ_0, and 1.6 λ_0 for both ε_r=9.6 and 6.4.



(a) (b)

Fig. 3. Measured E-plane radiation patterns for the three different substrate sizes of the rectangular patch antenna fabricated on (a) the Taconic CER-10 substrate (ε_r=9.6) and (b) the RF60A substrate (ε_r=6.4).

Fig. 3(a) and (b) show the measured E-plane radiation patterns of the patch antenna fabricated on the Taconic CER-10 substrate (ε_r=9.6) and RF60A substrate (ε_r=6.4) for the three different substrate sizes, respectively. Fig. 3(a) and (b) show similar direction of peak gain versus the substrate size because the effective dielectric constant of the RF60A with the substrate thickness of 1.52 mm at the resonant frequency of 5.4 GHz is the same as that of the CER-10 with the substrate thickness of 1.58 mm at the resonant frequency of 5.0 GHz. The radiation patterns of microstrip patch antennas are mainly determined by the effective dielectric constant of a grounded dielectric substrate. The largest F/B ratio due to the large broadside gain and the minimum back lobe gain is obtained when the substrate size is 0.8 λ_0. Table I summarizes the simulated and measured results of the radiation characteristics of a patch antenna for the three different substrate sizes with ε_r=9.6 and 6.4, respectively.

TABLE I

Simulated and Measured Results of the Radiation Characteristics of a Patch Antenna for the Three Different Substrate Sizes with ε_r=9.6 and 6.4

Substrate type	Substrate size (λ_0)		3 dB beam width (°)	E-plane radiation pattern		H-plane radiation pattern		Broadside gain (dBi)	Back lobe gain (dBi)
				Direction of peak gain(°)	peak gain (dBi)	Direction of peak gain(°)	peak gain (dBi)		
ε_r=9.6 (CER-10)	0.8	sim.	90	1	5.38	0	5.38	5.38	-13.82
		exp.	100	-2	4.89	2	4.96	4.88	-11.73
	1.0	sim.	143	39	5.27	0	4.41	4.41	-6.67
		exp.	109	6	5.31	5	5.62	5.30	-8.22
	1.3	sim.	121	40	5.81	21	3.17	3.02	-7.12
		exp.	66	39	5.44	27	2.90	2.12	-10.30
ε_r=6.4 (RF60A)	0.8	sim.	88	1	5.78	0	5.77	5.77	-14.52
		exp.	99	7	5.40	5	5.34	5.38	-15.05
	1.0	sim.	142	34	5.45	-2	5.15	5.14	-6.92
		exp.	95	12	5.70	13	5.72	5.55	-10.49
	1.3	sim.	136	38	6.00	-14	4.04	3.94	-7.61
		exp.	139	39	5.77	20	4.15	3.26	-7.78

3. Conclusion

The radiation characteristics of a microstrip patch antenna are investigated systematically for various sizes of a square grounded dielectric substrate with various dielectric constants and resonant frequencies. The excellent agreement between the simulation and experiment results shows that the largest front-to-back ratio is obtained for the substrate size of 0.8 λ_0 due to the large broadside gain and the minimum back lobe gain. The radiation characteristics of a microstrip patch antenna versus the grounded dielectric substrate size are mainly determined by the effective dielectric constant of a grounded dielectric substrate.

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Acknowledgments

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