A High-Gain Microstrip Patch Array Antenna Using a Superstrate Layer

Wonkyu Choi, Yong Heui Cho, Cheol-Sik Pyo, and Jae-Ick Choi

A dielectric superstrate layer above a microstrip patch antenna has remarkable effects on its gain and resonant characteristics. This paper experimentally investigates the effect of a superstrate layer for high gain on microstrip patch antennas. We measured the gain of antennas with and without a superstrate and found that the gain of a single patch with a superstrate was enhanced by about 4 dBi over the one without a superstrate at 12 GHz. The impedance bandwidths of a single patch with and without a superstrate for VSWR < 2 were above 11%. The designed 2×8 array antenna using a superstrate had a high gain of over 22.5 dB and a wide impedance bandwidth of over 17%.

Keywords: High-gain, broadband, superstrate layer, microstrip antenna, stacked patch.

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I. Introduction

Recently, microstrip antennas having attractive features, such as low profile, light weight, and easy fabrication, are being widely used. Microstrip antennas also possess major shortcomings, such as narrow impedance bandwidth and low efficiency and gain, which seriously limit their application. Many broadband techniques for microstrip antennas have been reported [1], [2], and to overcome the disadvantage of low gain, some papers have proposed gain enhancement methods using multiple superstrates [3], [4]. However, the presence of superstrates above an antenna may adversely affect the antenna's basic performance characteristics, such as gain, radiation resistance, and efficiency. For this reason, it is important to analyze superstrate effects, so adequate superstrate parameters can be chosen to enhance gain and radiation efficiency. It has been reported that high gain can be achieved if the substrate and superstrate layers are used appropriately [3]. This paper compares the gain of a single patch with a superstrate with that of a single patch without a superstrate and reports the experimental results for a 2×8 array antenna with a superstrate and a 4×8 array antenna without a superstrate. We also present the details of the proposed antenna design.

II. Design of the Antenna Element and Simulation Results

Figure 1 depicts the proposed configuration designed to achieve a high gain single element antenna. Except for the superstrate, the radiating element itself is composed of the layer structure described in [5]. As Fig. 1(a) shows, the lower patch and feeding line are on the substrate with $\varepsilon_r = 2.17$

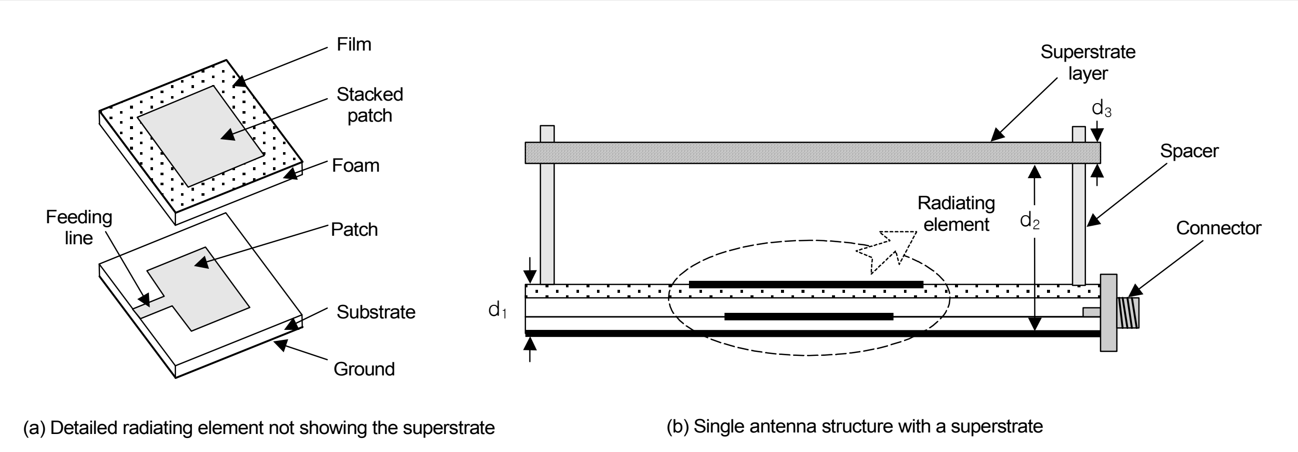


Fig. 1. Detailed radiating element not showing the superstrate and a single antenna structure with a superstrate.

and thickness = 0.508 mm, and the stacked patch on the thin film is supported by foam (ε_r = 1.06, 2 mm). Being very thin (0.04 mm) with respect to the wavelength, the film hardly affects radiation efficiency. Figure 1(b) shows the whole antenna structure for high gain. It is composed of the radiating element and the superstrate with ε_r = 6.4 and thickness d_3 = 1.27 mm (0.13 λ_g at 12 GHz). The superstrate is placed above the radiating patch at a distance d_2 = 12.75 mm (0.51 λ_0 at 12 GHz), where λ_0 is the wavelength in free space and λ_g is the wavelength in the medium of the superstrate (ε_r = 6.4). Once d_1 and d_3 are specified, d_2 can be chosen through trial and error for high gain. With a configuration like that in Fig. 1(b), it is convenient to adjust the distance d_2. By simply adjusting the distance d_2, the resonance condition for high gain can be obtained.

The resonance condition for high gain can be satisfied as d_1 is electrically a quarter wavelength and d_2 is half a wavelength [3], [4], [6]. However, for a microstrip patch antenna, d_1 with a λ_g/4 thickness is too thick. In this case, problems such as high surface wave and cross-polarization can occur. To overcome these problems, [7] reported that the optimal gain can be obtained by adjusting the distance d_2 for various thicknesses of d_1. Therefore, for different thicknesses of d_1 and d_3, there is a different resonance thickness d_2.

Based on the geometry shown in the Fig. 1, the simulation results using the commercial tool ENSEMBLE are shown in Fig. 2. In Fig. 2, the gain of a single patch with a superstrate is compared with that of a single patch without a superstrate. With a superstrate, the gain was about 13.9 dBi and without a superstrate, it was about 9.3 dBi. Thus, a gain enhancement of about 4 dBi was obtained over the gain of the patch without a superstrate at 12 GHz. The impedance bandwidths of single patches with and without a superstrate for VSWR < 2 were above 11%.

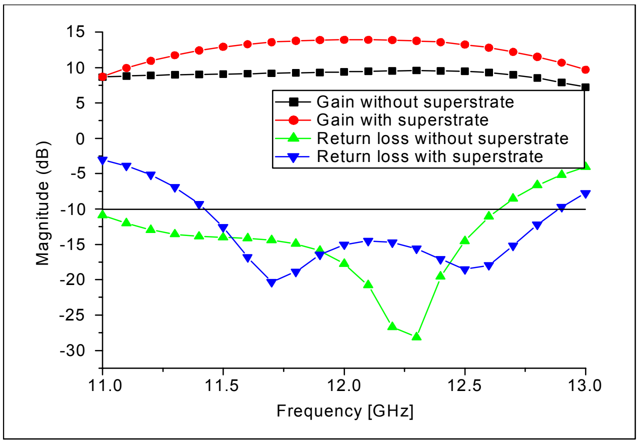


Fig. 2. Simulated results of the single patch with and without the superstrate.

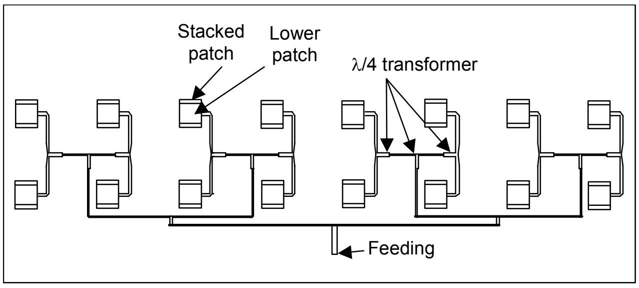


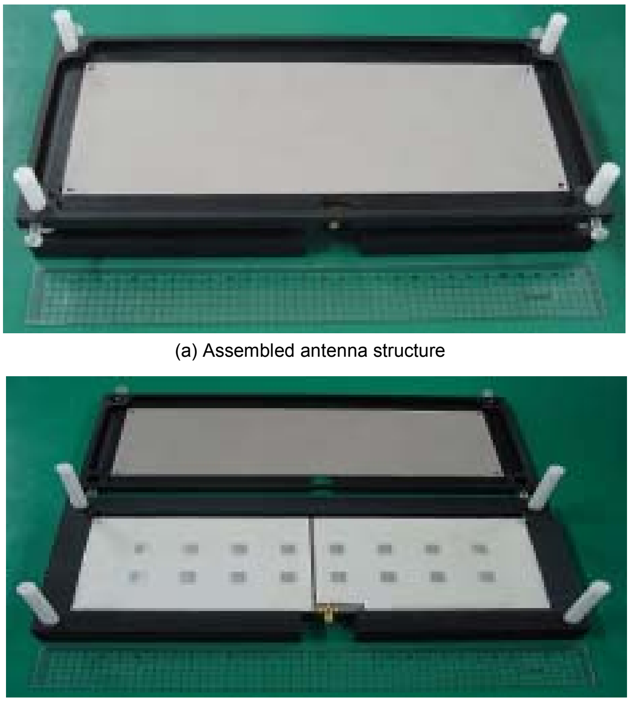
Fig. 3. The 2×8 array structure not showing the superstrate.

III. Design of Array Antenna

Figure 3 shows the designed array structure. The array was designed using a single radiating element (Fig. 1(b)) and corporate feeding method. The element spacing of this array antenna was 1.16 λ_0 at 12 GHz to minimize coupling. Although the element spacing in the array was wider than the wavelength in free space, the grating lobes were reduced by the superstrate.

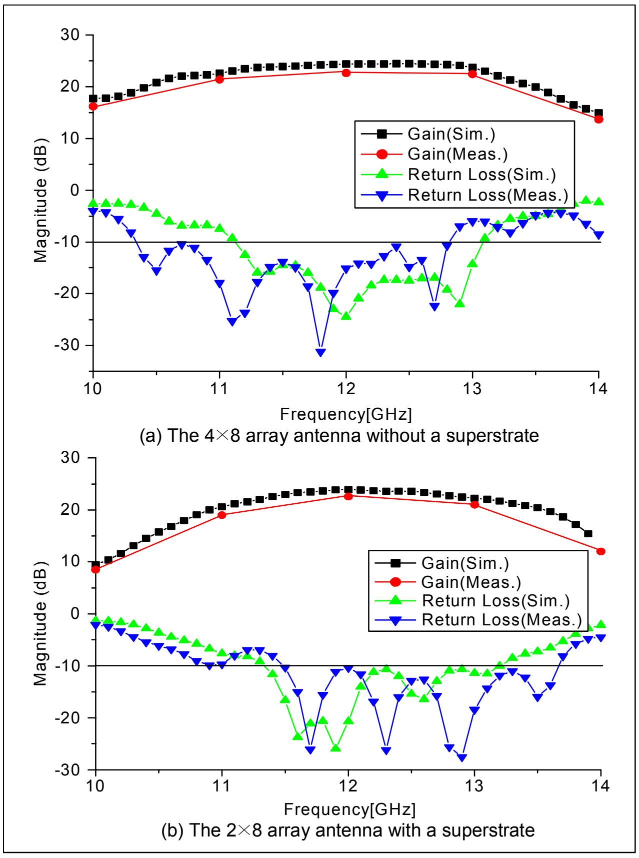
IV. Fabrication and Measurement

For this investigation, we fabricated a 2×8 array antenna with a superstrate and a 4×8 array antenna without a superstrate. Figure 4 shows a photograph of the fabricated 2×8 array antenna with a superstrate. We compared the measured results with the simulation results (Fig. 5) and measured the radiation patterns at 12 GHz (Fig. 6).


(a) Assembled antenna structure

(b) Disassembled antenna structure

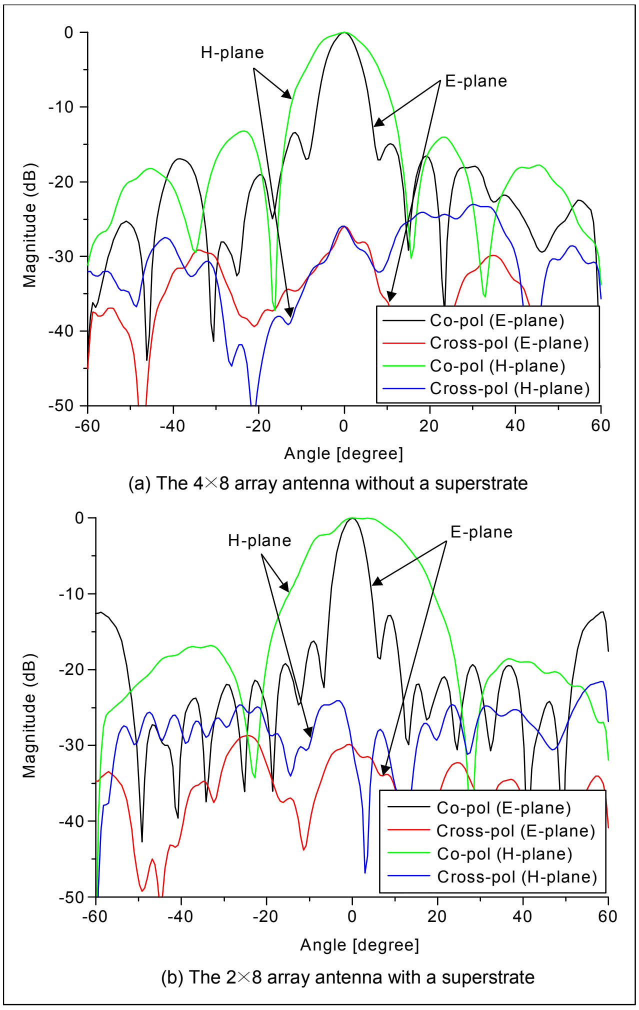
Fig. 4. Photograph of the fabricated 2×8 array antenna with a superstrate.



(a) The 4×8 array antenna without a superstrate

(b) The 2×8 array antenna with a superstrate

Fig. 5. Simulated and measured results of an antenna with and without a superstrate.



(a) The 4×8 array antenna without a superstrate

(b) The 2×8 array antenna with a superstrate

Fig. 6. Measured radiation patterns of an antenna with and without a superstrate at 12 GHz.

For the 4×8 array antenna without the superstrate, the sidelobe level was lower than -12 dB and the cross-polarization level was lower than -25 dB for the broadside direction. The half power beamwidths were about 7° in the E-plane and 13.5° in the H-plane. Similarly, for the 2×8 array antenna with the superstrate, the sidelobe level was lower than -12 dB and the

Table 1. Comparison for impedance bandwidth and gain.

Array antenna	Return loss bandwidth		Gain (12 GHz)	
	Simulation	Measurement	Simulation	Measurement
4×8 Antenna without superstrate	11.15-13.05 GHz (15.7%)	10.35-12.8 GHz (21.1 %)	24.3 dBi	22.6 dBi
2×8 Antenna with superstrate	11.35-13.2 GHz (15.1%)	11.45-13.65 GHz (17.5%)	23.9 dBi	22.65 dBi

Table 2. Comparison for radiation pattern.

Array antenna	Sidelobe level	Cross-pol level	Half-power beamwidth	
			E-plane	H-plane
4×8 Antenna without superstrate	Below -12dB	Below -25dB	About 7°	About 13.5°
2×8 Antenna with superstrate	Below -12dB	Below -30dB	About 5.5°	About 20.8°

cross-polarization level was lower than -30 dB for the broadside direction. The half power beamwidths were about 5.5° in the E-plane and 20.8° in the H-plane. The gains of both antennas were about 22.6 dBi in the former and 22.65 dBi in the latter at 12 GHz.

The experimental impedance bandwidths for VSWR<2 were both above 17%. A summary of the designed antennas is given in Tables 1 and 2. The tables reveal that the designed 2×8 array antenna with the superstrate had almost the same results as those of the 4×8 array antenna without the superstrate.

V. Conclusion

This paper introduced experimentally the effect of a superstrate layer for high gain on a microstrip patch antenna. The radiating element with broadband and high radiation efficiency was designed to enhance the narrow bandwidth characteristic by a superstrate with high permittivity. We compared the gain of a single patch with a superstrate to that of a single patch without a superstrate and gave the experimental results of a 2×8 array antenna with a superstrate and a 4×8 array antenna without a superstrate. The designed 2×8 array antenna using a superstrate had a high gain of over 22.5 dBi and a wide impedance bandwidth of over 17%. The proposed antenna will be useful for high gain systems requiring a broadband.

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