The Radiation Characteristics of a Linear Phased Array Antenna using Inductor Loaded Patch Antennas

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1. Introduction

To obtain high gain and wide bandwidth, electrically thick substrates are used in microstrip patch antennas. The increase in substrate thickness, however, tends to increase surface waves. A microstrip patch antenna has a strong radiation along the horizontal plane. To reduce the radiation in the horizontal plane, the technique by placing shorting pins between the patch and the ground has been investigated [3]. The excitation of surface waves and radiation in the horizontal plane lead to enhance the mutual coupling between antenna elements, which results in the decrease of the side lobe level (SLL) and the variation of the main beam gain for the variation of the main beam direction. The electromagnetic band gap (EBG) structures are applied to the phased array antenna (PAA) to improve the performance [4, 5]. This paper proposes the use of an inductor loaded patch antenna as an antenna element of PAAs in order to improve their radiation characteristics by the suppression of mutual coupling.

We investigate the radiation characteristics of PAAs with an inductor loaded patch antenna as an antenna element by experiment and simulation using HFSS (High Frequency Structure Simulator). Section 2 presents the design parameters used for two different types of PAAs. In section 3, simulated and experimental results on the performance of a conventional PAA and an inductor loaded patch PAA are presented and compared. Finally, section 4 concludes this paper.

2. Design of a Linear PAA using Inductor Loaded Patch Antennas

We present design parameters of a probe fed conventional patch PAA and a probe fed inductor loaded patch PAA of 7×1 elements on a high dielectric substrate. Fig. 1(a) and (b) show the fabricated linear 7-elements PAAs equidistantly positioned along the E-plane with a conventional patch antenna and a 5×2 inductor loaded patch antenna as an antenna element with the distance between the antenna centers of 0.7 λ_0, respectively. CER-10 used in this paper has a dielectric constant, ε_r, of 10.2, a loss tangent of 0.0035, and a thickness of 3.2 mm. The resonant frequency of the patch antenna is 5 GHz. The conventional patch size is 7.6 mm × 6.1 mm. The 5×2 inductor loaded patch size is 27.5 mm × 11 mm and pin radius is 1.0 mm. Grating lobe peaks will not appear in the visible region for E-plane scanning angular sector of $-25° < \theta < 25°$ with element spacing of 0.7 λ_0 [6].

3. Performance of an Inductor Loaded Patch PAA

The performance of a conventional patch PAA and an inductor loaded patch PAA was measured and simulated in terms of the active reflection coefficient and the active element pattern [7, 8].

3.1 Active Reflection Coefficient

Fig. 2(a) and (b) show the comparison of the measured and simulated results of the active reflection coefficient of a conventional patch PAA and an inductor loaded patch PAA, respectively. The experimental results show good agreement with the simulated results. The criterion of the active reflection coefficient is determined as -10 dB. The active reflection coefficient of a conventional PAA is larger than -10 dB for the E-plane scanning angular sector of $-11° < \theta < 11°$ in Fig. 2(a). The results demonstrate the impedance mismatch of fully excited and scanned phased array. The active reflection coefficient of an inductor loaded patch PAA is less than -10 dB for the whole range of the E-plane scanning angular sector in Fig. 2(b).

3.2 Active Element Pattern

Fig. 3(a) and (b) show the measured active element patterns of the center element and the average active element patterns in the E-plane of a conventional patch PAA and an inductor loaded patch PAA, respectively. The average active element pattern is smoother than the active element pattern of the center element. The significant dips near ±11°, ±34°, and ±65° in the active element pattern of the center element of a conventional patch PAA are observed, while no significant dips in that of an inductor loaded patch PAA are observed in Fig. 3(a). The radiated field amplitude at ±90° of an inductor loaded patch PAA is less than 10 dB compared to that of a conventional patch PAA, which is an indication for the suppressed radiation of an inductor loaded patch PAA in the horizontal plane.

3.3 Radiation Pattern

Fig. 4(a) and (b) show the calculated radiation patterns in the E-plane for the main beam direction of 0°, 11°, and 25° of a conventional patch PAA and an inductor loaded patch PAA, respectively. The calculated radiation pattern is obtained by multiplying the measured average active element pattern by the array factor[6]. The radiation characteristics of an inductor loaded patch PAA are compared to those of a conventional patch PAA. Scanning loss curve ($\cos\theta$) was plotted as dotted lines. In the case of an inductor loaded patch PAA, the main beam peaks follow this curve nicely. The results are summarized and compared in Table 1.

The variation of the main beam gain of a conventional patch PAA and an inductor loaded patch PAA due to the variation of the main beam direction is 4.15 dB and 0.37 dB, respectively. The increase of the side lobe gain of a conventional patch PAA is 11.37 dB, while that of an inductor loaded patch PAA is only 0.59 dB for the variation of the main beam direction. The SLL is defined as the ratio of the maximum value of the main lobe to the maximum value of the largest side lobe and expressed in dBc. The decrease of the SLL of a conventional patch PAA is 15.52 dB, while that of an inductor loaded patch PAA is only 0.64 dB for the variation of the main beam direction. The SLL of an inductor loaded patch PAA is much improved than that of a conventional patch PAA at the main beam direction of 25°, because the grating lobe of an inductor loaded patch PAA is reduced by the suppressed radiation in the horizontal plane.

4. Conclusion

The radiation characteristics of a conventional patch PAA and an inductor loaded patch PAA are measured and compared. The performance of an inductor loaded patch PAA is much improved than that of a conventional patch PAA because the mutual coupling between the adjacent antenna elements is very small. The radiation characteristics of an inductor loaded patch PAA show the superior performance such as low variations of the main beam gain and the SLL below 0.7 dB for the variation of the main beam direction from 0° to 25°.

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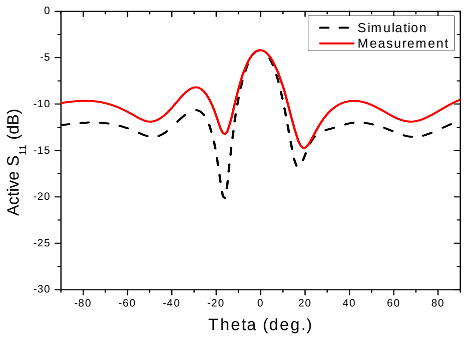
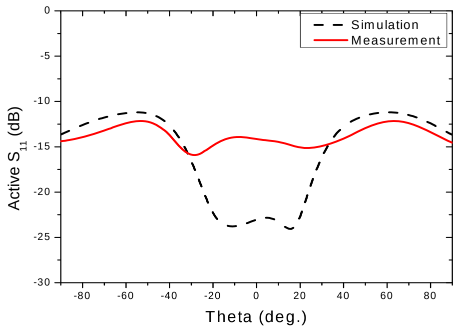
(a)

(b)

Figure 1: The fabricated linear 7-element PAAs equidistantly positioned along the E-plane with (a) a conventional patch antenna and (b) a 5×2 inductor loaded patch antenna as an antenna element with the distance between the antenna centers of 0.7 λ_0

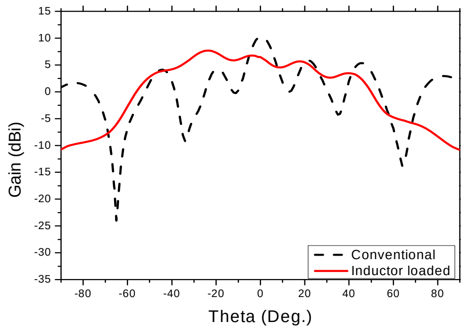


(a)

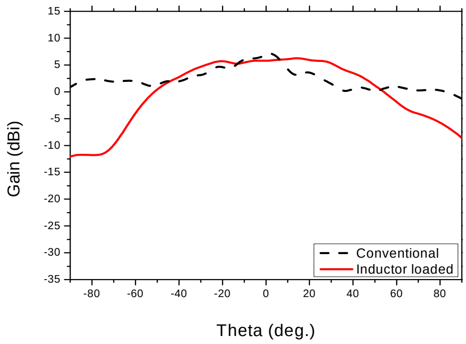


(b)

Figure 2: Simulated and measured active reflection coefficient of the center element in (a) a conventional PAA and (b) an inductor loaded patch PAA

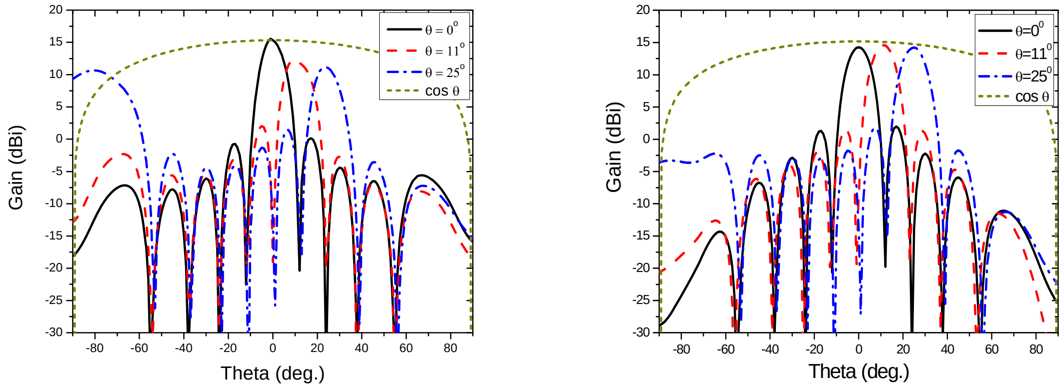


(a)



(b)

Figure 3: (a) Measured active element patterns of the center element and (b) average active element patterns in the E-plane of a conventional PAA and an inductor loaded patch PAA



(a) (b)

Figure 4: Calculated radiation pattern in the E-plane for the direction of the main beam of 0°, 11°, and 25° of (a) a conventional patch PAA and (b) an inductor loaded patch PAA

Table 1: Calculated radiation characteristics of a conventional patch PAA and an inductor loaded patch PAA

	A conventional patch PAA				An inductor loaded patch PAA			
Main Beam direction (°)	Main beam gain (dBi)	Side lobe gain (dBi)	SLL (dBc)	3dB Beam width (°)	Main beam gain (dBi)	Side lobe gain (dBi)	SLL (dBc)	3dB Beam width (°)
0	15.33	-0.71	16.04	10	14.27	1.17	13.1	10
11	12.26	2.05	10.21	13	14.59	1.58	13.01	10
25	11.18	10.66	0.52	10	14.22	1.76	12.46	11

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