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Performance Evaluation of Thinning on Multifunctional Array Antennas

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ABSTRACT: The array covers the L-band and S-band range frequencies used for multifunctional applications and operate between 1.61 GHz and 2.492 GHz. The quad frequency antenna resonates at four frequencies 1.176 GHz, 1.575 GHz, 1.6 GHz, and 2.492 GHz, which cover the L-band and S-band frequencies. The configurations of both antennas are layered patches. Performance measurements of the two antenna arrays have been compared, including side lobe level, return loss, and gain. Both the antennas are fabricated using affordable, easily accessible FR4 Epoxy. By implementing thinning for both array antennas, gain values are observed, and good performances are obtained.

1. INTRODUCTION

In [1], a triple-band phased array antenna with slots that produce multiple resonant frequencies has been proposed for the X, K, and Ku bands. An antenna array in [2] that operates within 9.3 GHz and 9.4 GHz consists of both parallel and series feed elements. One face of the antenna radiates from a single band, while the other face of the double-sided antenna array presented in [3] radiates across both frequency bands. An array of cavity-backed is depicted in [4] where an air cavity has been added between the radiating element and ground plane to boost the antenna's gain.

(a) (b)

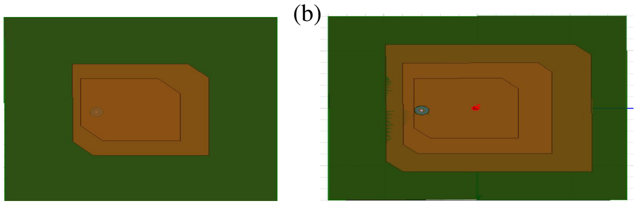

FIGURE 1. The structure of the proposed antenna element. (a) Dual frequency antenna. (b) Quad frequency antenna.

The two antenna arrays with various phased frequency ranges for operation are proposed. The antennas, which measure 80 mm in length and width, have been designed using an FR4 substrate. The board has layers that are each 4 mm thick, and its relative dielectric constant is 4.4. The dual band antenna in Figure 1(a) is capable of operating in both the RADAR frequency bands of L and S. The upper patch is 27 mm $\times$ 29.1 mm in size, while the bottom patch is 39.4 mm $\times$ 40 mm. The four frequencies are depicted in Figure 1(b). Lower, middle, and top patches have measurements of 55.2 mm $\times$ 55.2 mm, 39.4 mm $\times$ 40 mm, and 26 mm $\times$ 28.1 mm, respectively. The inter-element spacing of the array of antennas is set at 0.5 times the open space wavelength [5–13]. Both of the antenna structures were subjected to the simulation using the thinning effect at various levels, and the antennas have been evaluated at different frequencies in terms of gain.

2. DESIGN AND CONFIGURATION OF ANTENNA

The suggested stacked array consists of 24 antenna elements aligned in a 3×8 matrix arrangement of which dual frequencies are obtained as shown in Figure 2(a), and another array that has quad frequency of operation uses three rectangular radiating elements as shown in Figure 2(b). The fabricated model of quad-frequency and dual and stacked patch antennas are shown in Figures 3(a) and 3(b). Coaxial feed is utilized to trigger the antenna elements. Ansys HFSS simulator tool is to design antenna array. To obtain the finest performance of the antenna array, the concept of inter-element spacing of 0.5λ is implemented [14–18].

The values of array elements were calculated using the following equations [19–26].

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

$$\varepsilon_{\mathit{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

$$L_{\mathit{eff}} = \frac{c}{2f_o\sqrt{\varepsilon_{\mathit{eff}}}} \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{\mathit{eff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{\mathit{eff}}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

$$L = L_{\mathit{eff}} - 2\Delta L \tag{5}$$

The proposed elements and arrays are depicted in Figures 1 and 2.

The prototypes of antennas are shown in Figure 3.

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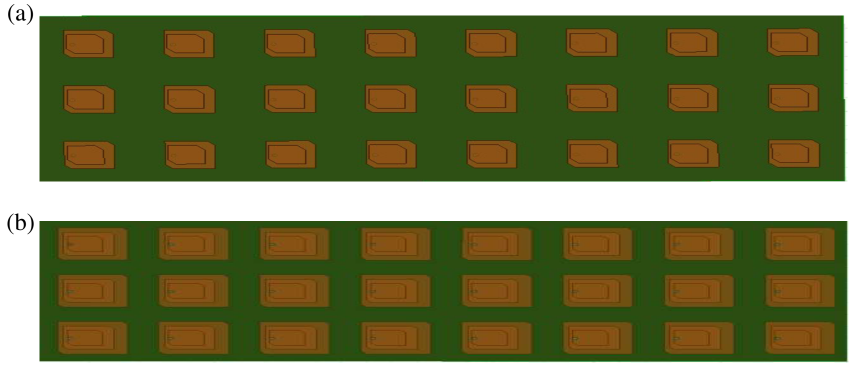

FIGURE 2. Proposed array antenna geometry. (a) Array of dual frequency antenna. (b) Array of quad frequency antenna array.

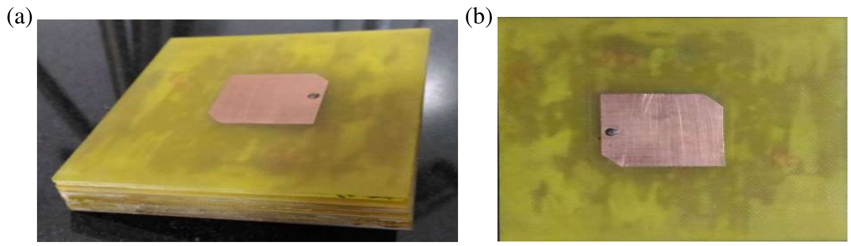

FIGURE 3. The fabricated antenna models. (a) Dual frequency fabricated model. (b) Quad frequency fabricated model.

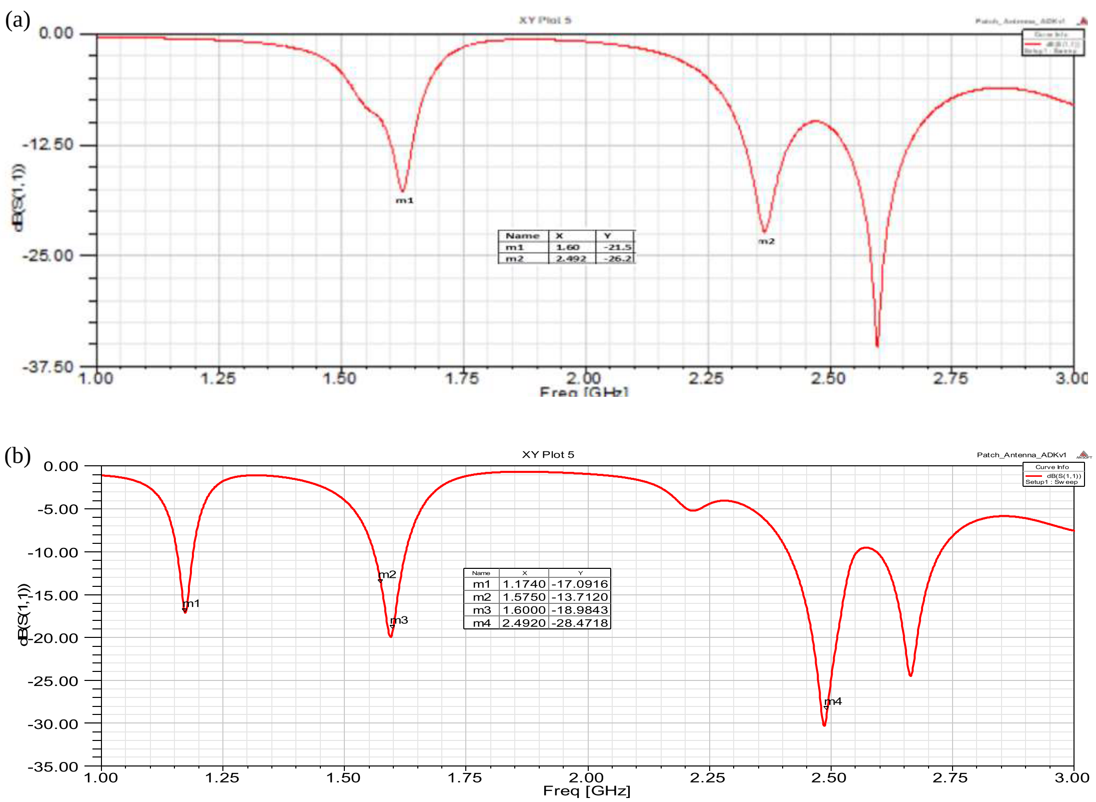

FIGURE 4. The return loss plot of antenna element. (a) Dual frequency antenna. (b) Quad frequency antenna.

3. RESULTS

The performances of the proposed arrays are analyzed using ANSYS HFSS. The thinning effect has been proposed on both antennas, and the impact on gain at various frequencies is considered. The concept of thinning involves the reduction of active elements in the antenna array without causing major degradation in the system performance for the purpose of cost effective mechanism.

The case study is categorized into four different instances. In instance 1, a complete array is considered and in instance 2 reduction of 15 percent of the total elements, i.e., 4 elements.

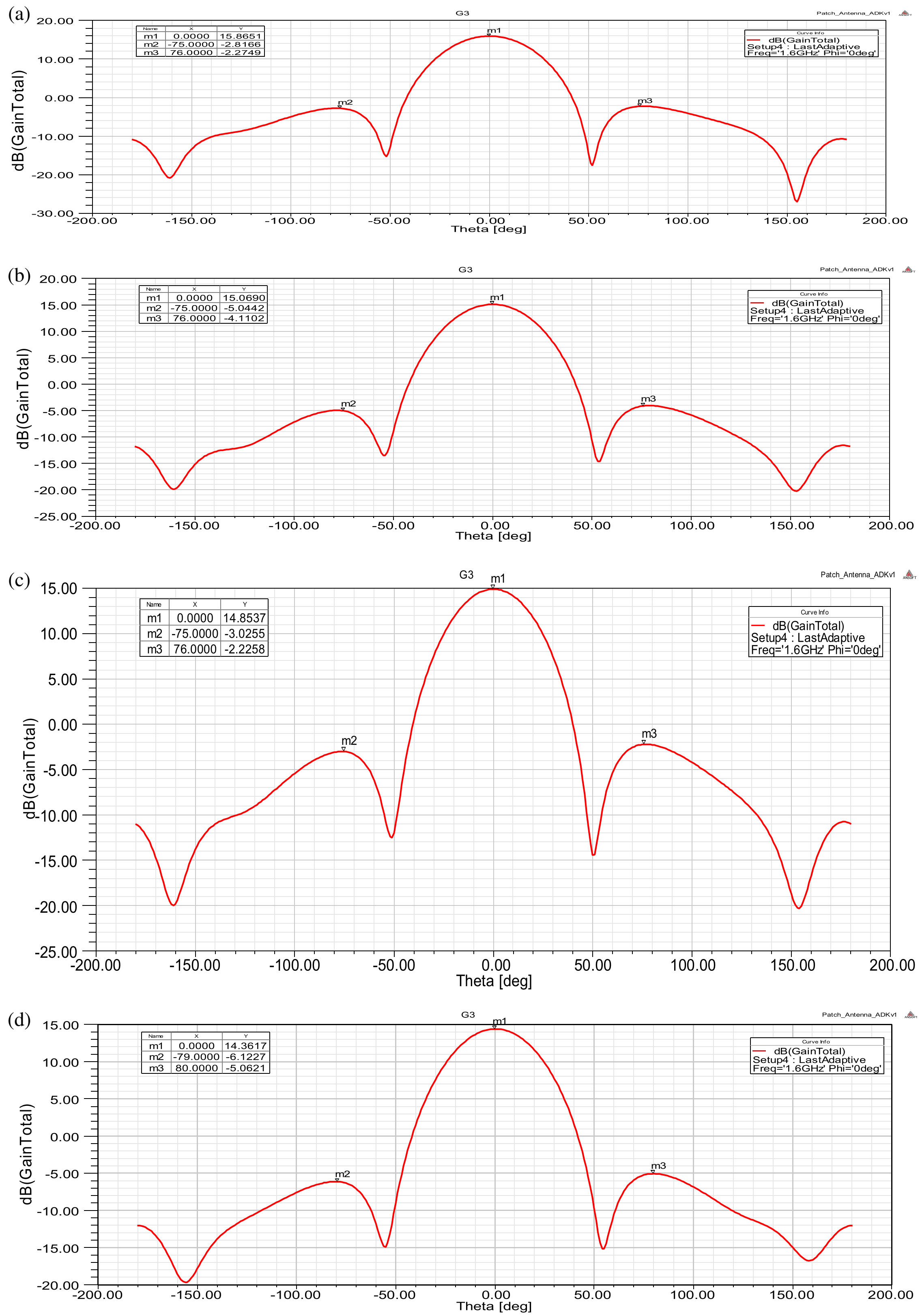

FIGURE 5. Gain at 1.6 GHz. (a) The full array. (b) The thinning of 15 percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

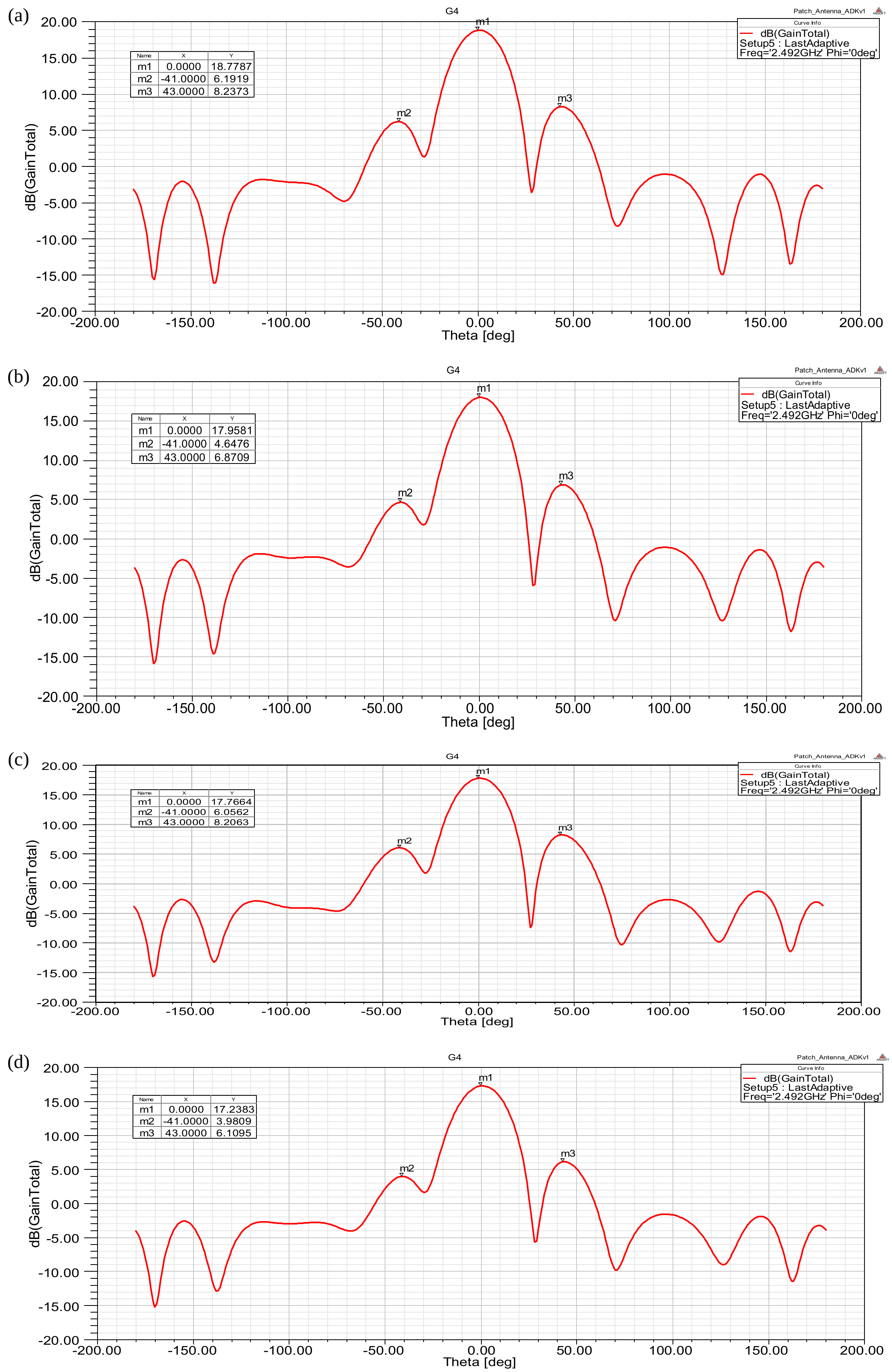

FIGURE 6. The gain near 2.492 GHz. (a) The full array. (b) The thinning of 15 percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

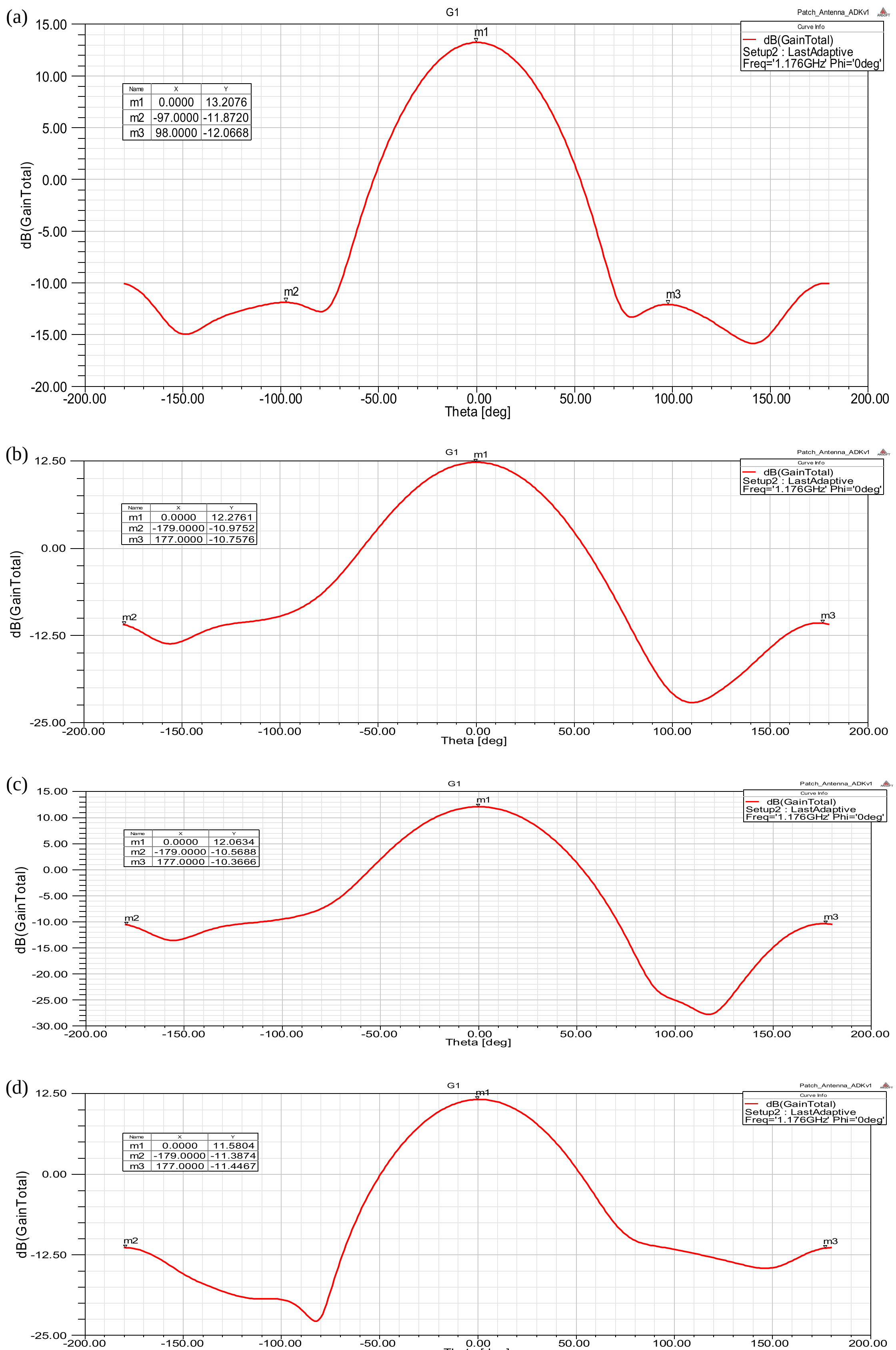

FIGURE 7. The gain near 1.176 GHz. (a) The full array. (b) The thinning of 15 percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

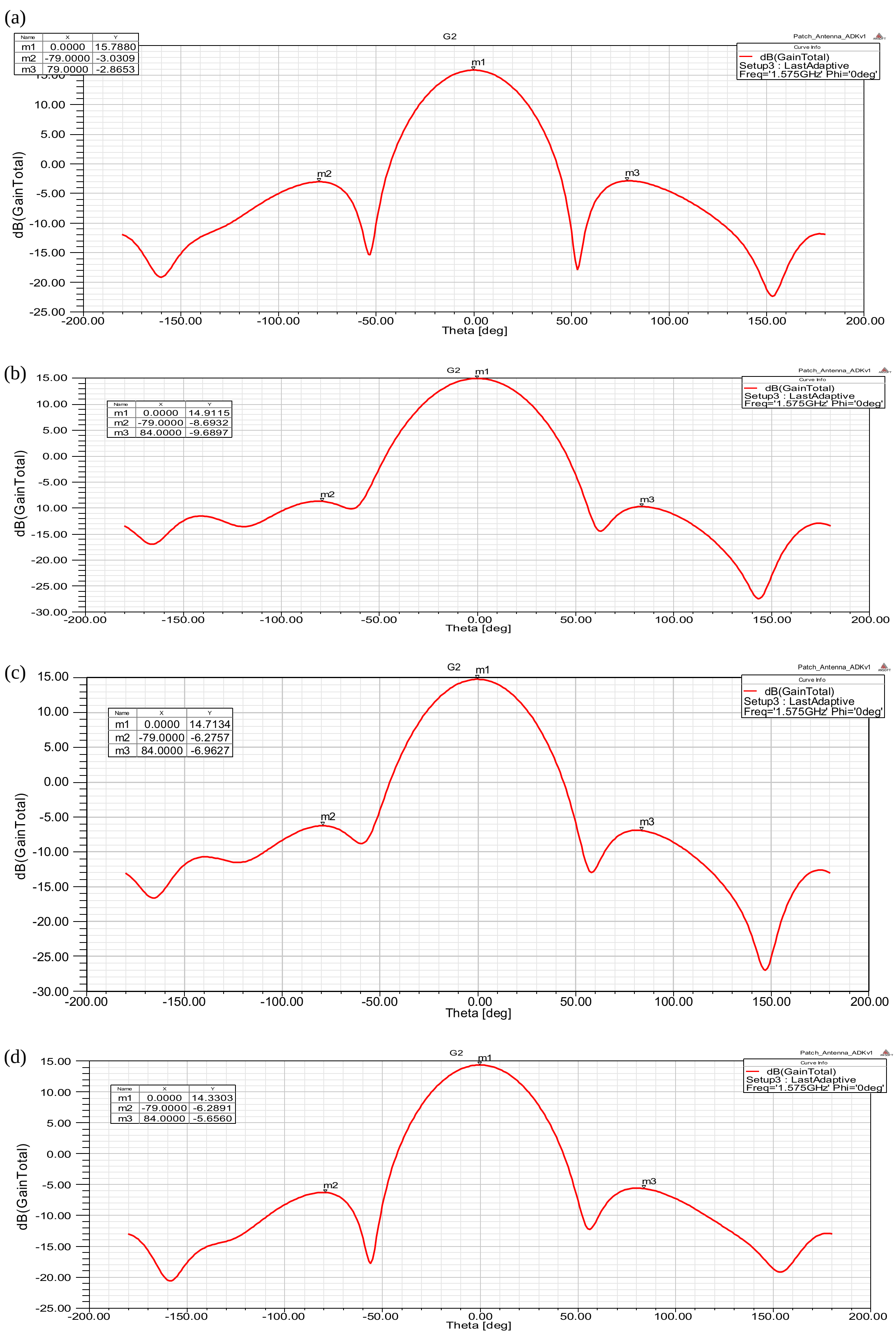

FIGURE 8. The gain at 1.575 GHz. (a) The full array. (b) The thinning of 15 ,percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

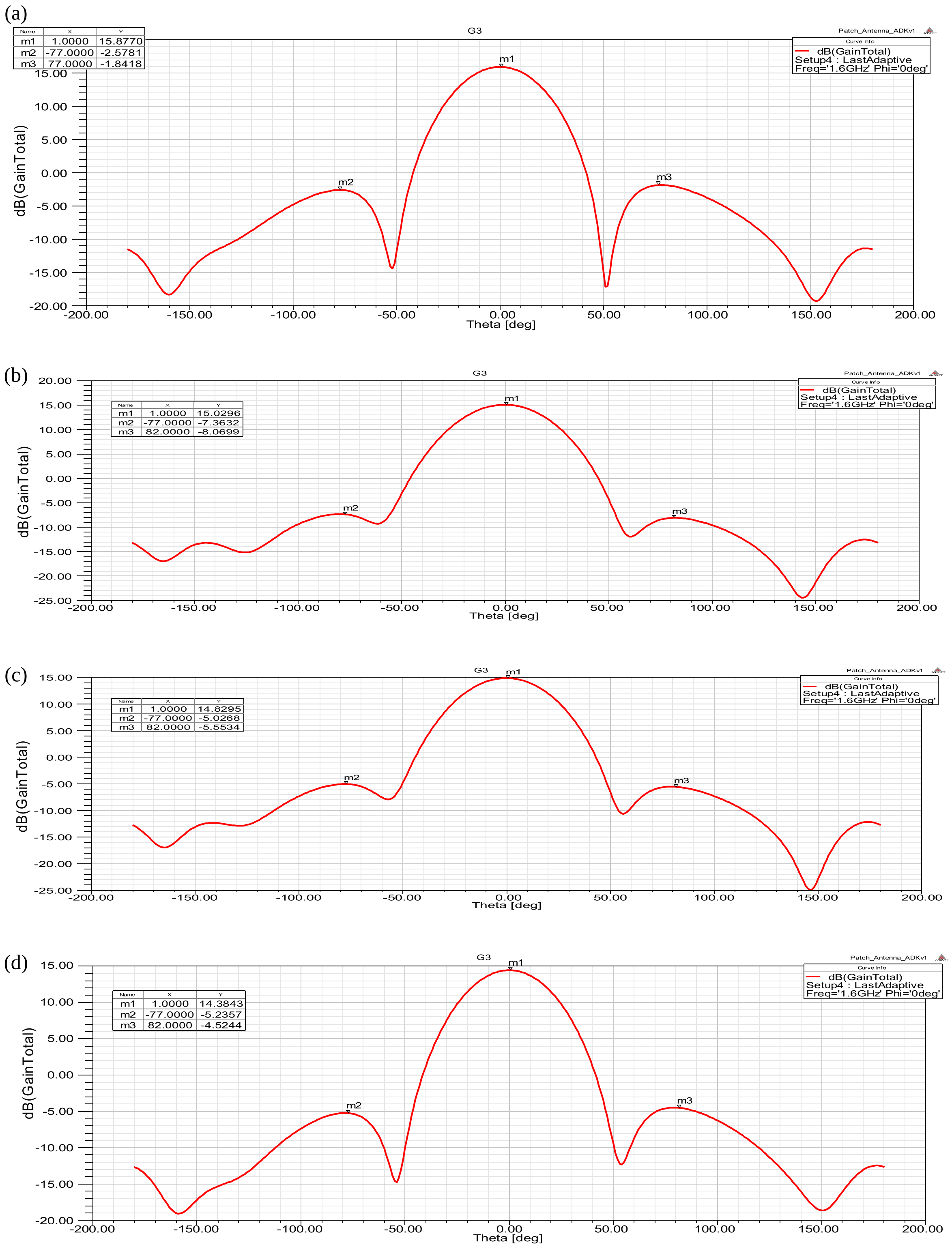

FIGURE 9. Gain at 1.6 GHz. (a) The full array. (b) The thinning of 15 percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

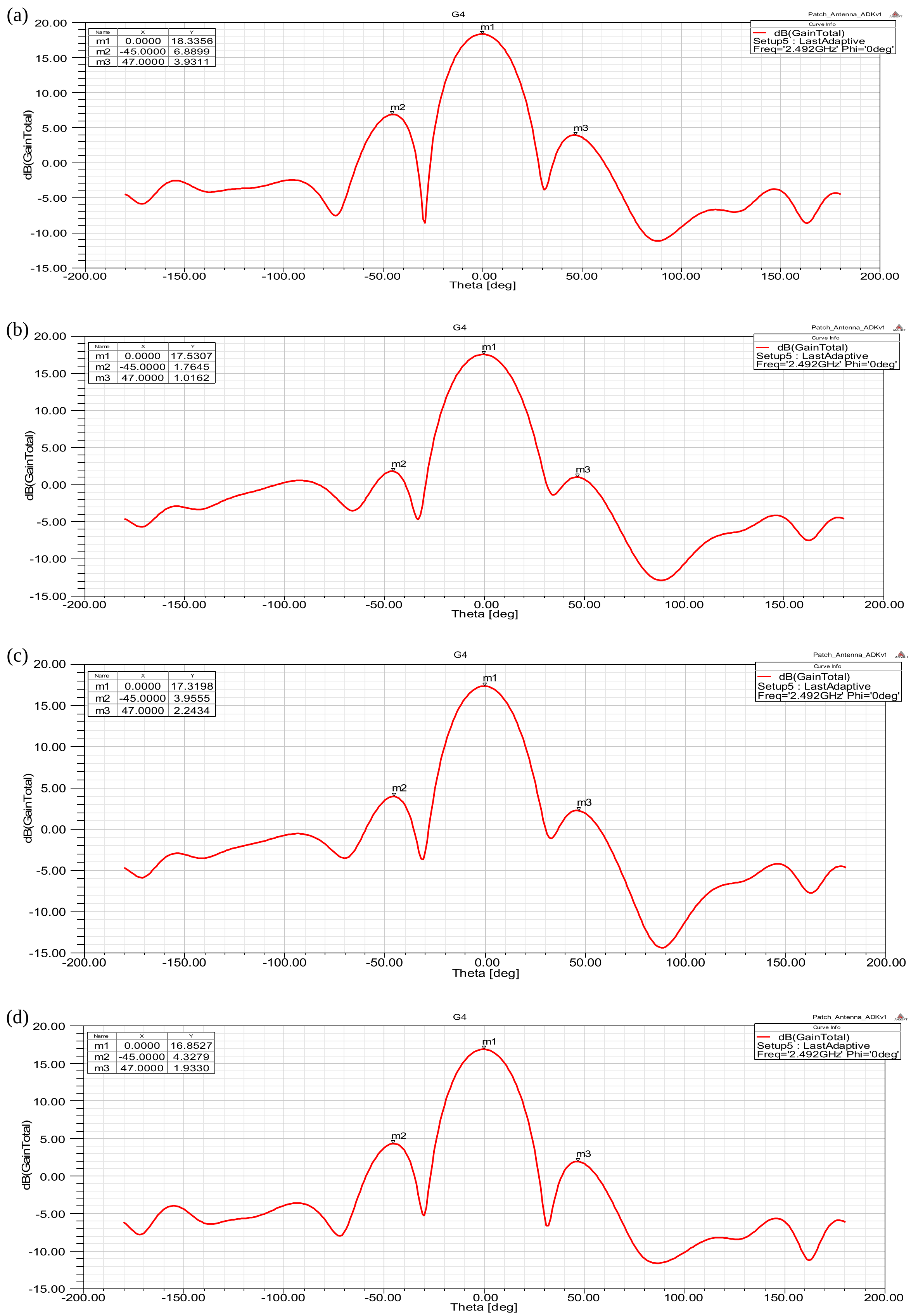

FIGURE 10. Gain at 2.492 GHz. (a) The full array. (b) The thinning of 15 percent. (c) The thinning of 20 percent. (d) The thinning of 30 percent.

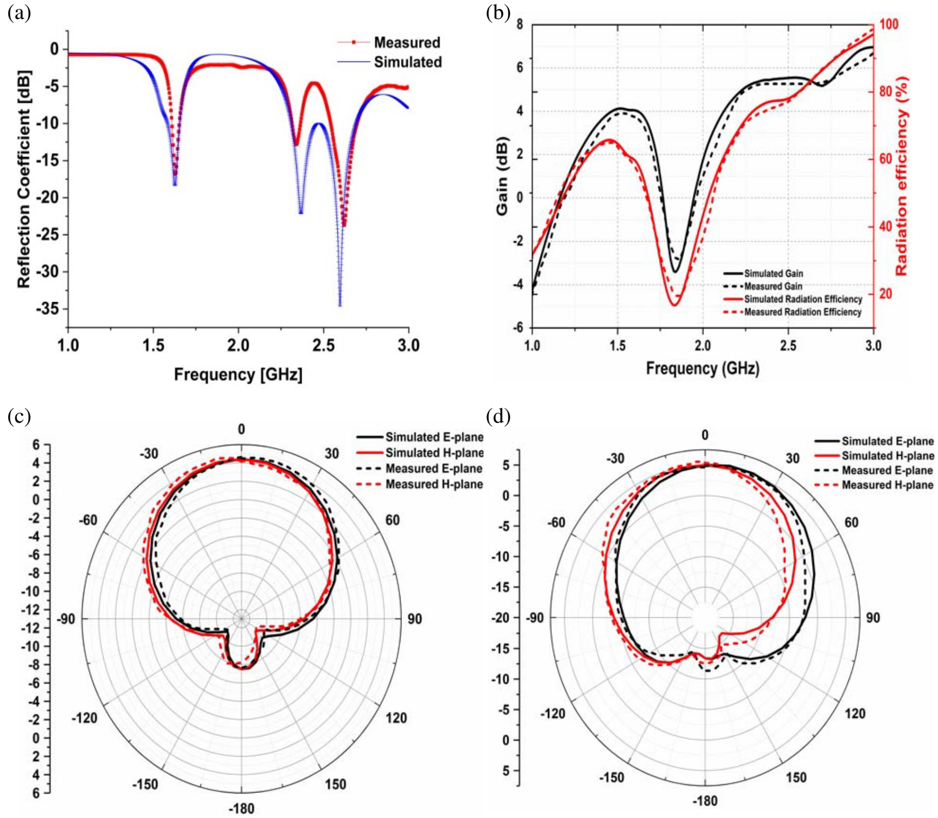

FIGURE 11. Comparison of simulated and measured results of dual frequency antenna. (a) Return loss. (b) Gain & radiation efficiency. (c) Radiation pattern at 1.6 GHz. (d) Radiation pattern at 2.494 GHz.

Similarly, in instance 3 the reduction of 20 percent of the elements, i.e., 5 elements, and in instance 4 reductions of 30 percent, i.e., 7 elements of the array, are done randomly.

After the application of thinning, the gain variations at 1.6 GHz are of 0.7 dB, 1 dB, 1.5 dB for 15 percent, 20 percent, and 30 percent, respectively. The return loss for the antenna arrays is laid out in Figure 4. Dual and quad frequency antennas resonate at respective frequencies of 1.60 GHz and 2.492 GHz, and quad frequencies of 1.176 GHz, 1.575 GHz, 1.60 GHz, and 2.492 GHz.

Figure 5(a) illustrates the gain of the entire array of dual frequency stacked patch antennas at 1.6 GHz, which is 15.8 dB. Figure 5(b) shows the gain variation after thinning 15 percent of the array elements, which reduces the array's four elements, and Figure 5(c) shows the gain variation after thinning 20 percent of the array elements, which results in a gain variation about 1 dB. Applying the thinning effect results in a gain fluctuation of 1.5 dB for a 30% array, as shown in Figure 5(d).

Figure 6(a) demonstrates the gain of dual frequency array at 2.492 GHz which shows 18.7 dB without the use of thinning. However when thinning is used for 15%, 20%, 25%, and 30%, the gain is reduced by 0.8 dB, 1 dB, and 1.5 dB, respectively, which are illustrated in Figures 6(b), 6(c), and 6(d).

The gain of a four-element array at 1.176 GHz, shown in Figure 7(a), is 13.2 dB, and as shown in Figures 7(b), 7(c), and 7(d), after applying the thinning, gain changes of 1.0 dB, 1.2 dB, and 1.8 dB are seen for 15 percent, 20 percent, and 30 percent thinning, respectively.

Figure 8(a) reveals the gain of a array at 1.575 GHz earlier than the thinning effect applied. Figures 8(b), 8(c), and 8(d) illustrate the gain variations that are observed after the thinning effect is applied for reductions of 15 percent, 20 percent, and 30 percent, respectively.

Figure 9(a) demonstrates the gain at 1.6 GHz of quad antenna, without the thinning effect. Gain variations of 0.7 dB, 1 dB, and 1.4 dB for 15 percent thinning, 20 percent thinning, and 30 percent thinning, respectively, are observed and shown in Figure 9(b), Figure 9(c), and Figure 9(d).

Before using the thinning operation, the 2.492 GHz quad-frequency array has a gain of 18.3 dB, as illustrated in Figure 10(a). Following the execution of the thinning method, the gain variations for 15 percent, 20 percent, and 30 percent thinning are shown in Figures 10(b), 10(c), and 10(d) to be 0.8 dB, 1.1 dB, and 1.5 dB, respectively.

It appears that there are some slight changes in the gains of antenna array after implementing the thinning which is useful for cost effective mechanism. The comparison of simulated and measured results of the dual frequency antenna is shown in Figure 11.

The comparison of simulated and measured results of the quad frequency antenna is shown in Figure 12.

The experimental measurement setup of both dual frequency and quad frequency antennas are shown in Figure 13.

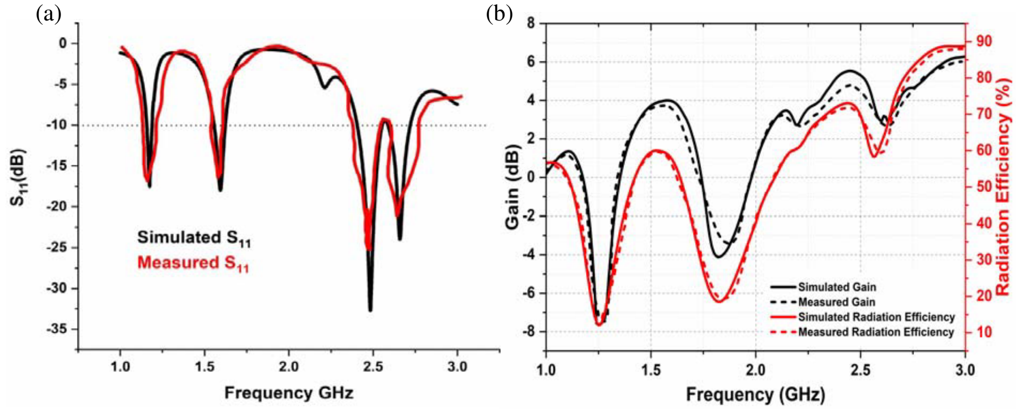

FIGURE 12. Comparison of simulated and measured results of quad frequency antenna. (a) Return loss. (b) Gain & radiation.

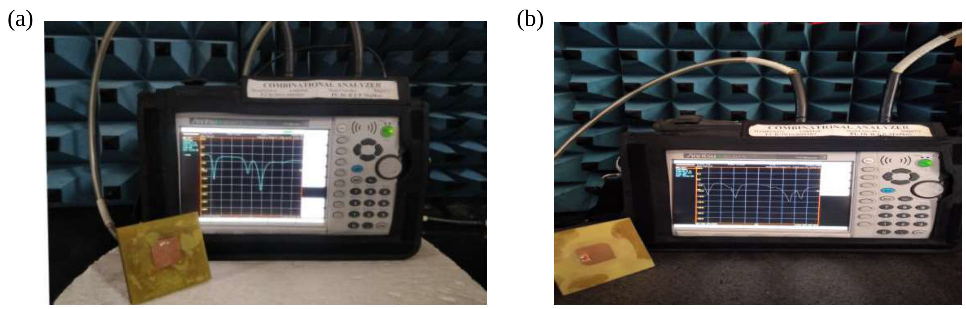

FIGURE 13. Experimental set up of fabricated antennas. (a) Dual frequency antenna. (b) Quad frequency antenna.

4. CONCLUSION

In this study, a 3×8 array antenna that resonates at two frequencies and a quad frequency array antenna that resonates at four frequencies are proposed. The two arrays with thinning effects' evaluation metrics are seen. In four scenarios, instance 1 was treated as an absolute array; instance 2 had 15 percent fewer elements; instance 3 had 20 percent fewer elements; and instance 4 had 30 percent elements which were considered randomly. Upon the application of the thinning effect, it can be seen that instance 2 has a gain variation of 0.7 dB; instance 3 has a gain variation of 1 dB; and instance 4 has a gain variation of 1.5 dB. For cost-effective mechanisms, the use of the thinning effect for antenna arrays is essential.

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