A High-Gain Grid Array Antenna for 60-GHz Antenna-in-Package Applications

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***Abstract*—This paper presents a high-gain grid array antenna (GAA) on FERRO A6M low temperature co-fired ceramic (LTCC) for 60-GHz antenna-in-package (AiP) applications. The high-gain GAA includes four sub-antennas. Dimensions of the sub-antenna are 15 × 15 × 1 mm^3, which is composed of four subarrays. Measured results show that the sub-antenna features impedance bandwidth (BW) 50 – 65.6 GHz, 3-dB gain BW 58.5 – 67 GHz with the maximum gain 15 dBi at 62 GHz, and vertical beams in the broadside direction at 60 GHz. The high-gain GAA has dimensions of 30 × 30 × 1 mm^3. Simulated results show that it has impedance BW 55.8 – 63.5 GHz, 3-dB gain BW 56.8 – 64 GHz with the maximum gain of 21.4 dBi at 61 GHz, and vertical beams in the broadside direction at 60 GHz. It is a capable candidate for 60-GHz AiP applications.**

***Index Terms*—grid array antenna; low temperture co-fired ceramic; 60-GHz**

I. Introduction

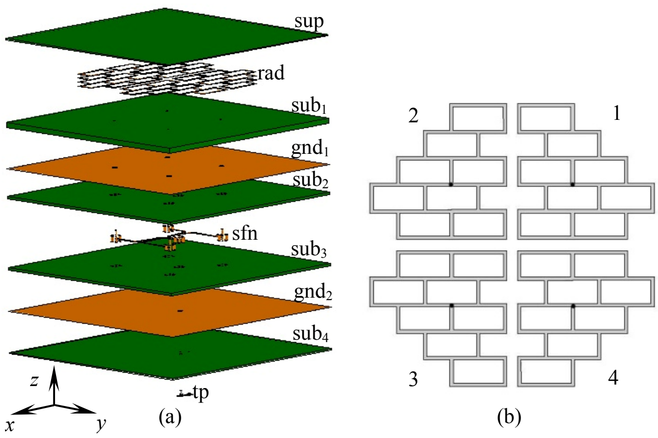
The 60-GHz band is allocated for short-range, high bit rate wireless communication. Nearly all kinds of antennas can be used for this purpose, among which the grid array antenna (GAA) stands out as a capable candidate because of its high gain, wide impedance bandwidth (BW) and simple structure. It was invented by Kraus [1] in 1964, further improved by Nakano [2] [3], and brought to the stage of millimeter-wave (mmWave) antenna-in-package (AiP) applications by Zhang [4-8]. GAA is an array antenna composed of interconnected grids, in which the length of short sides is half guided wavelength while the long side is twice as long. The short sides function as radiating elements that carry in-phase current. The electromagnetic (EM) field generated by the in-phase current adds constructive in the far-field region, which is accountable for the co-polarization. The long sides of each grid carry out-of-phase current that are accountable for the cross-polarization. In this paper, we first propose a high-gain MS GAA which includes sub-antennas. Each of the sub-antennas is a GAA with sub-arrays. The Ferro A6M low temperature co-fired ceramic (LTCC) is chosen as the substrate as well the package for its moderate permittivity (ε_r = 5.9), low loss (tan δ = 0.002) and the capability to realized multilayer structure. The paper is organized as follows: Section II introduces structures of the sub-antenna and the high-gain GAA, Section III presents the simulated and measured results, and Section IV concludes the paper.

II. Design of the High-Gain Grid Array Antenna

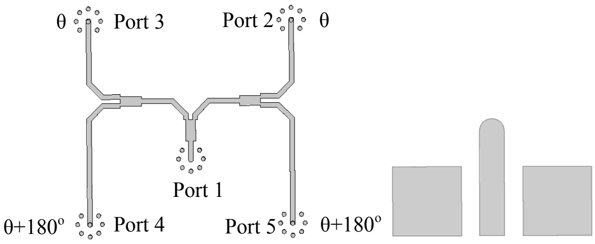
In this section, a GAA with four sub-arrays is introduced. Then the high-gain GAA which is an extension of the aforementioned prototype is designed.

A. Configuration of the Sub-Antenna

The AiP structure has dimensions of 15 mm × 15 mm × 1 mm. Fig. 1 (a) shows its exploded view. It consists of five ceramic (green color) and five metallic (yellow color) layers. All the metallic layers are made of 0.01 mm thick gold. The superstrate (sup) is 0.1 mm thick that prevents the radiating elements (rad) from being scratched. The radiating array (rad) is composed of 4 subarrays with separation g of 0.5 mm between the adjacent subarrays. The lengths of the short and long sides of each grid are s = 1.12 mm and l = 2.24 mm respectively. The width of the short side of each grid is made equal to that of the long side $w_s = w_l$ = 0.12 mm. The ceramic substrate layer (sub$_1$) is 0.4 mm thick. The metallic ground plane (gnd$_1$) is for the rad and the stripline feeding network (sfn). The ceramic substrates (sub$_2$ and sub$_3$) for the sfn have an equal thickness of 0.2 mm. As shown in Fig. 1 (c), the sfn has its input at Port 1 and outputs at Ports 2, 3, 4 and 5. The four output ports are connected to four subarrays in quadrants 1, 2, 3 and 4 respectively by four vias of length 0.6 mm through four circular openings on the gnd$_1$. The fencing vias of length 0.4 mm are located around each feeding via to connect gnd$_1$ and gnd$_2$. The 0.1 mm bottom ceramic layer (sub$_4$) provides the substrate for the ground-signal-ground (GSG) testing pad (tp) or the power, signal and ground traces to be flip-chip bonded with the 60-GHz radio die.



(a) (b)

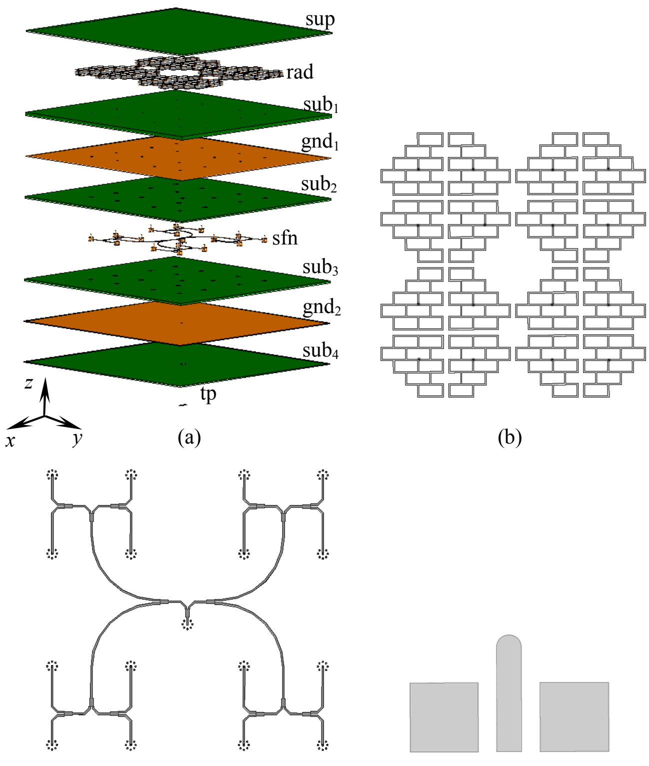


(c) (d)

Fig. 1. The sub-antenna: (a) exploded view, (b) radiating array, (c) stripline feeding network, and (d) testing pad.

B. Configuration of the High-Gain MS GAA

Fig. 2 (a) shows the exploded view of the high-gain MS GAA. It has dimensions of 30 mm × 30 mm × 1 mm^3. All the ceramic layers (green color) are FERRO A6M LTCC of thickness: superstrate (sup) 0.1 mm, substrate for the radiating array (sub_1) 0.4 mm, substrates for the stripline feeding network (sub_2 and sub_3) 0.2 mm respectively and substrate for the testing pad (sub_4) 0.1 mm. All the metallic layers (yellow color) are made of 0.01 mm thick gold. The radiating array (rad) is on the top (Fig. 1 (b)), it is composed of four copies of the radiating array shown in Fig. 1 (b), expecting 6 dB gain increment for the sub-antenna. The ground plane (gnd_1) for both the radiating array and the stripline feeding network (sfn) is below sub_1. The sfn is shown in Fig. 6 (c), by which larger attenuation for the input signal can occur because of the longer electric length of the sfn in Fig. 2 (c) than Fig. 1 (c). The testing pad (tp) on the bottom of the package shares the same ground plane (gnd_2) with the sfn. Transitions between different layers of signal traces are the same with the sub-antenna.



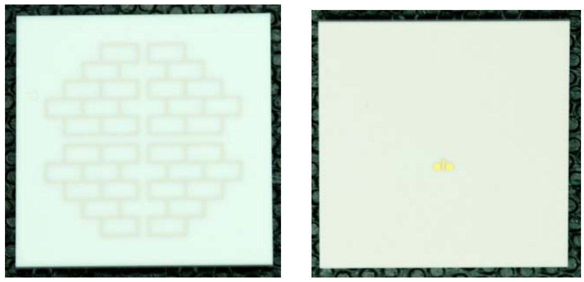
(a) (b)

(b) (c)

Fig. 2. The high-gain GAA: (a) exploded view, (b) radiating array, (c) stripline feeding network, and (d) testing pad.

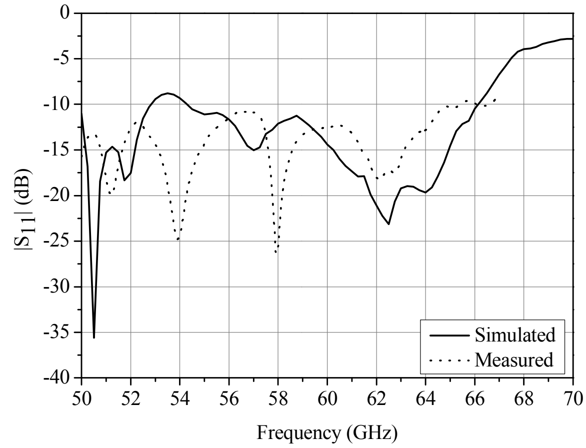
III. Simulated and Measured Performance

Fig. 3 shows the top and bottom view of the fabricated sub-antenna by VTT Finland. Measured results show that the sub-antenna has impedance BW 50 – 65.6 GHz in Fig. 4 (a), 3-dB gain BW 58.5 – 67 GHz with the maximum gain 15 at 62 GHz in Fig. 4 (b), and vertical beams in the broadside direction at 60 GHz in Fig. 4 (c) and (d).

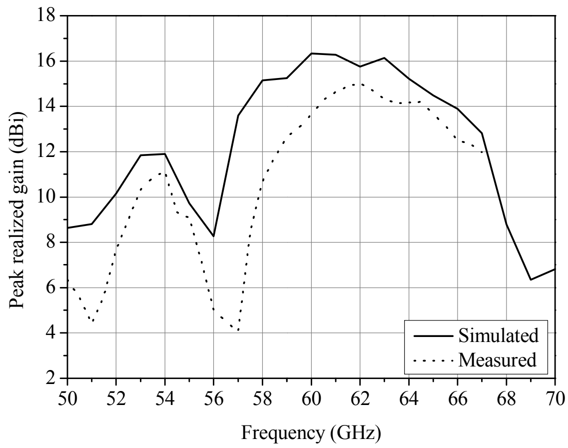


(a) (b)

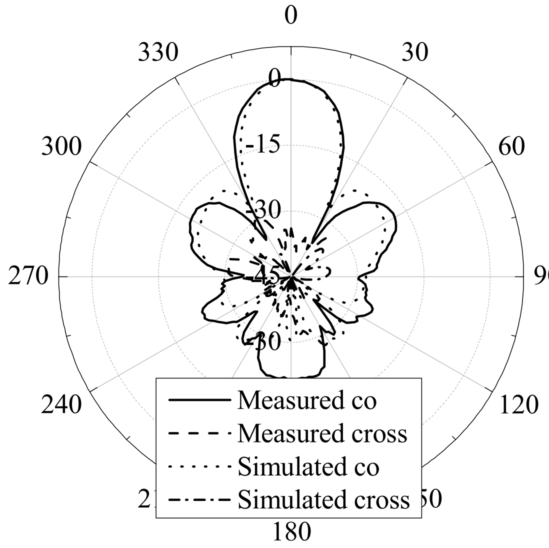
Fig. 3. Photographs of the fabricated sub-antenna: (a) top view and (b) bottom view.



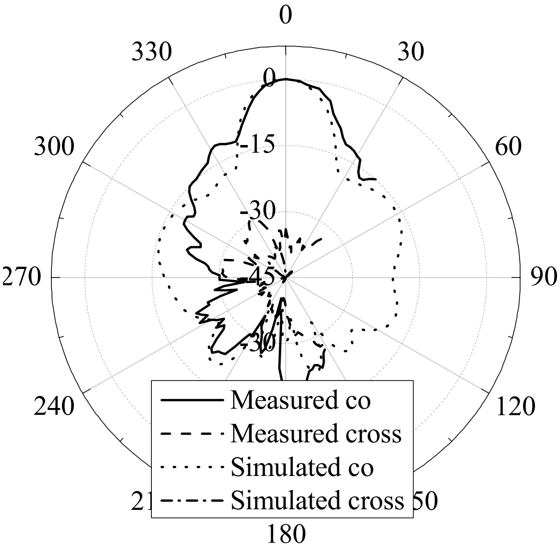
(a)



(b)



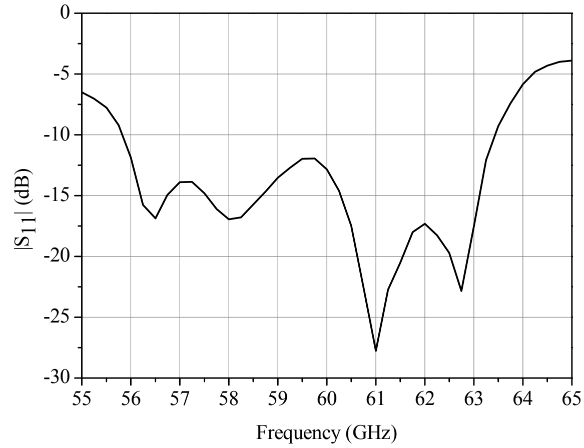
(c)



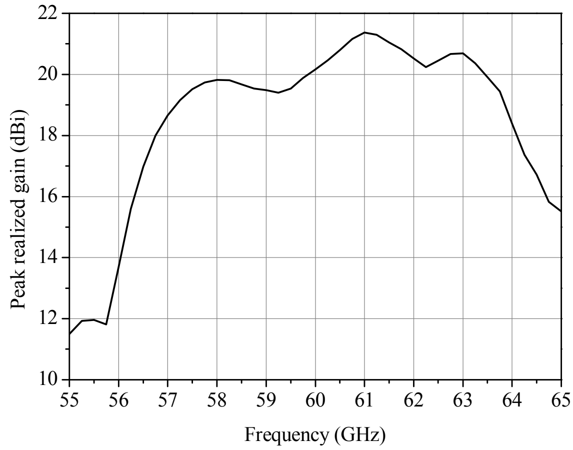
(d)

Fig. 4. Measured performance of the sub-antenna: (a) $|S_{11}|$, (b) peak realized gain, and 60 GHz radiation patterns at: (c) E-plane and (d) H-plane

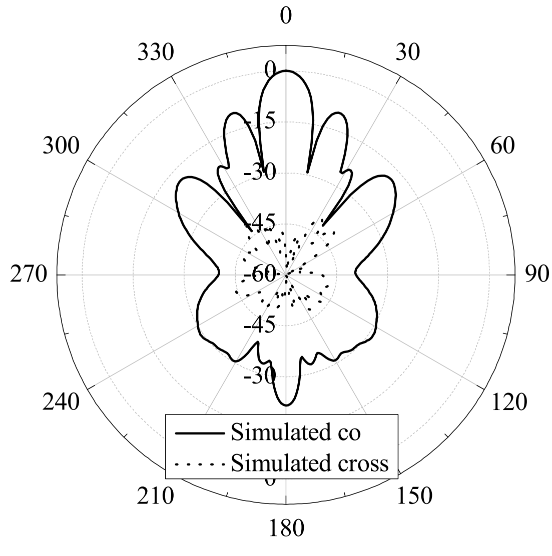
The high-gain GAA is now in fabrication. Simulated results show its impedance BW 55 – 64.6 GHz in Fig. 5 (a), 3-dB gain BW 56.8 – 64 GHz with the maximum gain of 21.4 dBi at 61 GHz in Fig. 5 (b), and vertical beams in the broadside direction at 60 GHz in Fig. 5 (c) and (d). It is a capable candidate for 60-GHz applications.



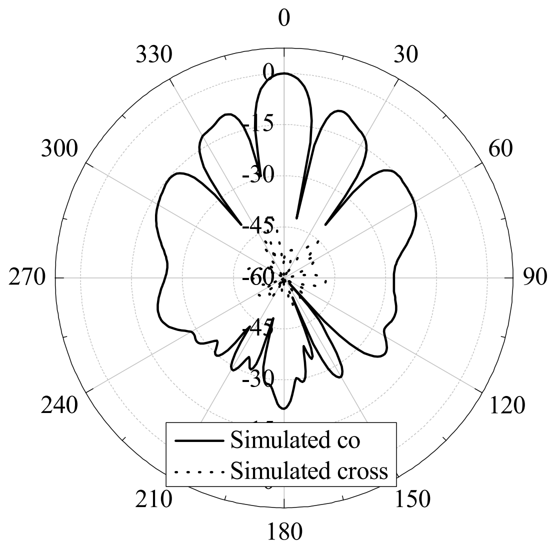
(a)



(b)



(c)



(d)

Fig. 5. Simulated performance of the high-gain GAA: (a) $|S_{11}|$, (b) peak realized gain, and 60 GHz radiation patterns at: (c) E-plane and (d) H-plane.

IV. CONCLUSION

This paper presents a design of high-gain GAA on Ferro A6M LTCC for 60-GHz AiP applications. Simulated and measured results show its satisfactory performance.

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