The Substrate and Ground Plane Size Effect on Radiation Pattern of 60-GHz LTCC Patch Antenna Array

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***Abstract*-The influence of finite substrate and ground plane size on the radiation pattern performance of L-probe feed thick patch antenna-in-package array in low-temperature co-fired ceramic (LTCC) for 60-GHz wireless communications is investigated and compared when the antenna array is with and without the soft surface structure, which is used to reduce surface wave effect and improve the antenna performance. It is shown that the effect of the substrate and ground plane size effect on the radiation patterns of the array is significant and the shape of the main lobe will be distorted obviously when the antenna array is without the soft surface structure. On the other hand, the antenna radiation performance will not be affected too much by the substrate and ground plane size when the soft surface structure is added into the antenna array to reduce surface wave effect.**

I. Introduction

Recently, there exists a surge of interest in wide unlicensed frequency band around 60 GHz for wireless short-range communications. The low-temperature co-fired ceramic (LTCC) multilayer technology based antenna-in-package (AiP) solutions has become a hot topic for 60-GHz applications [1]-[9]. Many types of antennas, such as a dipole, a slot, a patch, a helical, etc. [2]-[5], as the elements used in the design of 60-GHz LTCC arrays have been investigated. The patch antenna, because of its geometrical simplicity and other attractive features, has been widely used in the designs of the 60-GHz LTCC antenna arrays [6]–[8]. In [9], we proposed a wideband LTCC L-probe fed thick patch antenna for 60-Ghz applications and a soft surface was added to reduce the surface wave. For mobile terminals applications, the antennas or arrays need be integrated into the system mother board with a large substrate and ground plane size. Thus, it is necessary to study the effect of the substrate and ground plane size on 60-GHz LTCC antenna array characteristics.

In this paper, we investigate the effect of the substrate and ground plane size on the radiation performance of the 60-GHz L-probe fed thick patch antenna array in LTCC technology with and without the soft surface structure. It is shown that the effect of the substrate and ground plane size effect on the radiation patterns of the array is significant and the shape of the main lobe will be distorted obviously when the antenna array is without the soft surface structure. On the other hand, the antenna radiation performance will not be affected too much by the substrate and ground plane size when the soft surface structure is added into the antenna array.

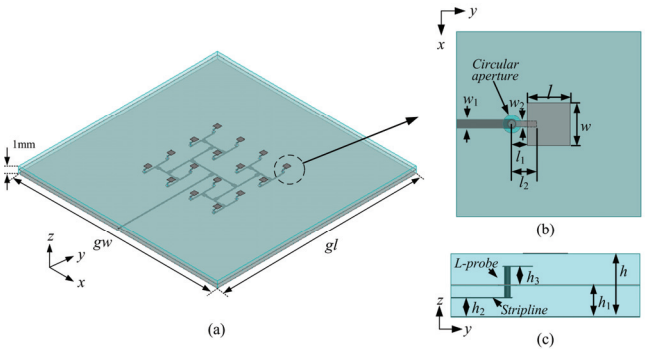

Fig. 1. Geometry of the 60-GHz LTCC based L-probe fed patch antenna array in [9], (a) 3D view of the array, (b) Top View of the single element, (c) Side View of the single element.

TABLE I Detailed L-probe Patch Antenna Dimensions

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
w	0.7	l	0.7
w_1	0.15	l_1	0.25
w_2	0.1	l_2	0.4
h	1	h_1	0.5
h_2	0.3	h_3	0.3

II. Antenna Geometry

The 60-GHz LTCC based L-probe fed patch antenna array which was proposed in [9] as shown in Fig.1. The multilayer LTCC substrate used is Ferro A6-M with dielectric permittivity ε_r=5.9 and loss tangent tanδ=0.001. The detailed dimensions of the array element are shown in Table I. The total thickness of the proposed array is 1 mm. The distance between the top rectangle patch and the top ground of the stripline feeding network is 0.5mm, which is about 10% free space wavelength (λ_0) at 60 GHz. The size of the substrate and ground is $gw \times gl$. In this work, the element spacing of 3.7 mm ($0.75 \times \lambda_0$) was chosen.

III. Effects of Substrate and Ground Plane Size on the Radiation Pattern of the Array Located in the Center of the Mother Board

A. Array Without the Soft-surface Structure

The effects of the substrate and ground plane size on the radiation pattern of the L-probe fed thick patch antenna array without any soft surface structure are investigated. The comparison of simulated radiation pattern in XoZ-plane and YoZ-plane of the array with different substrate and ground plane size at 60 GHz are shown in Fig. 2.

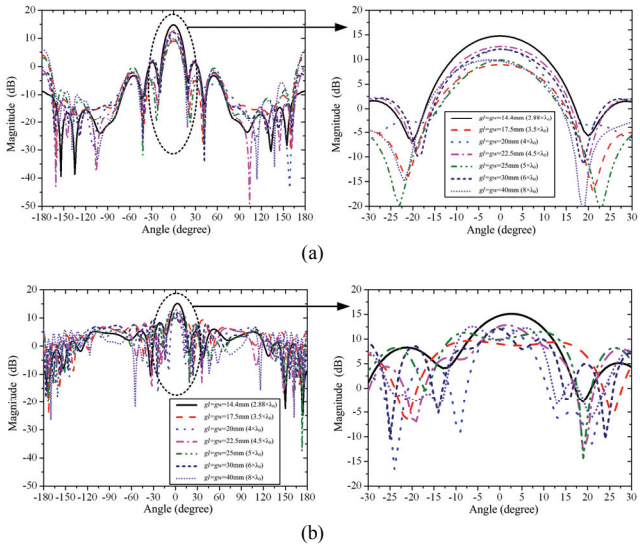

Fig. 2. The radiation pattern of the LTCC based L-probe fed patch antenna array for different substrate and ground plane size at 60 GHz, (a) XoZ-plane, (b) YoZ-plane.

As shown in Fig 2, with the substrate and ground plane size increasing, the shape of the main-lobe radiation pattern in XoZ-plane (H-plane) will not change too much. However, the main lobe shape of radiation pattern in YoZ-plane (E-plane) is changed obviously with the substrate and ground plane size. The E-plane radiation pattern is changed more significantly than H-plane radiation pattern. The distortion of the patch antenna array's radiation pattern with the substrate and ground size is due to the surface waves in the antenna array.

B. Array With the Soft-surface Structure

To reduce the surface wave effect and improve the radiation patterns performance of the array located on the large size of the substrate and ground, seven strip-shaped soft surface structures constituted of metal strips on top layer and via fences are loaded in the array. The top metal strip width of the proposed soft-surface structure is 1.4mm. The via fences are composed of a row of vias. Following the fabrication process requirement, the diameter of each via is 0.1mm, and the distance between the centers of two adjacent vias is 0.25mm. Fig. 3 shows the layout of the proposed array with soft surface structures on the large substrate and ground size.

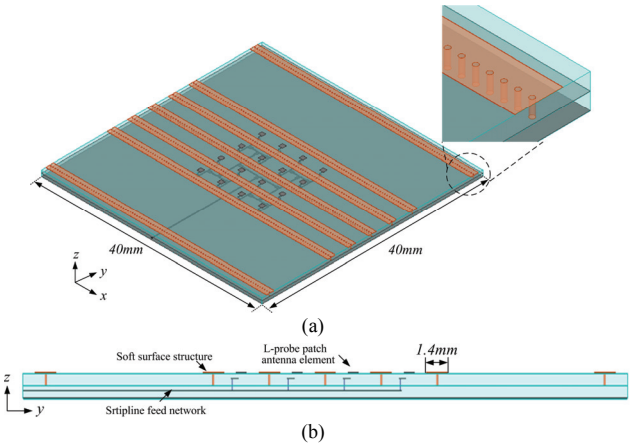

Fig. 3. Geometry of the LTCC based L-probe feed patch antenna array with soft-surface structures on the large substrate and ground size, (a) 3D view, (b) Side View.

Fig. 4 compares the simulated radiation patterns of the proposed arrays with or without the soft surface structure on the large substrate and ground size at 60GHz. For the array without soft surface structure, when the substrate and ground size is 40mm × 40mm ($8\lambda_0 \times 8\lambda_0$), the radiation pattern is distorted significantly. There is an obvious notch appeared at the broad direction (z-axis) in YoZ-plane (E-plane). Compared with the array without soft surface structure, it is very clearly seen form Fig. 4(b) that the radiation patterns performance of the array with soft surface structure is improved obviously, especially the radiation pattern in YoZ-plane. Therefore, for the array with the soft surface structure, the distortion of main lobe can be ignored; and good radiation pattern and high gain performances of the array on the large substrate and ground size can be achieved.

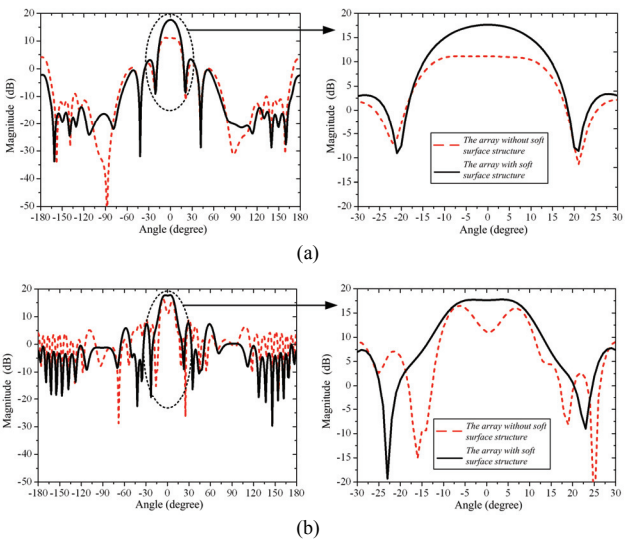

Fig. 4. Comparison of the radiation pattern at 60GHz between the proposed arrays without or with the soft surface structure on a large substrate and ground sizee, (a) XoZ-plane, (b) YoZ-plane.

IV. Conclusion

In this paper, the effect of the substrate and ground size on the radiation pattern of the 60-GHz L-probe fed thick patch antenna array in LTCC technology has been investigated. It has shown that the radiation pattern of the antenna array can

be improved significantly with the introduction of the soft surface structure to suppress the strong surface wave in the array.

ACKNOWLEDGMENT

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REFERENCES

[1] Y. P. Zhang and D. Liu, "Antenna-on-chip and antenna-in-package solutions to highly integrated millimeter-wave devices for wireless communications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 2830–2841, Oct. 2009.

[2] H. Chu, Y. X. Guo, and Z. Wang, "60-GHz LTCC wideband vertical off-center dipole antenna and arrays," *IEEE Trans. Antennas and Propag.*, vol. 61, no. 1, pp. 153–161, Jan. 2013.

[3] J. Xu , Z. N. Chen, X. Qing, and W. Hong, "Bandwidth enhancement for a 60 GHz substrate integrated waveguide fed cavity array antenna on LTCC," *IEEE Trans. Antennas Propag.*, vol. 59, no. 3, pp. 826-832, Mar. 2012.

[4] M. Sun, Y. Q. Zhang, Y. -X. Guo, M. F. K., L.C. Ong, and M. S. Leong, "Integration of circular polarized array and LNA in LTCC as a 60-GHz active receiving antenna," *IEEE Trans. Antennas Propag.*, vol. 59, no.8, pp. 3083-3089, Aug. 2011.

[5] C. Liu, Y. -X. Guo, X. Bao, and S. Q. Xiao, "60-GHz LTCC integrated circularly polarized helical antenna array," *IEEE Trans. Antennas Propag.*, vol. 60, no. 3, pp. 1329-1335, Mar. 2012.

[6] Y. Li ,Z. N. Chen, X. Qing, Z. Zhang, J. Xu, and Z. Feng, "Axial ratio bandwidth enhancement of 60-GHz substrate integrated waveguide-fed circularly polarized LTCC antenna array," *IEEE Trans. Antennas and Propag.*, vol.60, no. 10, pp. 4619-4626, Oct. 2012.

[7] H. Sun, Y.-X. Guo, and Z. Wang, "60-GHz circularly polarized U-slot patch antenna array on LTCC," *IEEE Trans. Antennas Propag.*, vol. 61, no. 1, pp. 430-435,Jan. 2013.

[8] S. B. Yeap, Z. N. Chen, and X. Qing, "Gain-enhanced 60-GHz LTCC antenna array with open air cavities," *IEEE Trans. Antennas Propag.*, vol.59, no. 9, pp. 3470-3473, Sep. 2011.

[9] L. Wang, Y.X. Guo, W.X. Sheng, "Wideband high-gain 60-GHz LTCC L-probe patch antenna array with a soft surface," *IEEE Trans. Antennas and Propag.*, vol.61, no.4, pp. 1802-1809, Apr. 2013.