Integration of grid array antenna in chip package for highly integrated 60-GHz radios

Guo, Y. X.; Wai, L. L.; Sun, Mei; Zhang, Yue Ping; Chua, Kai Meng

2009

Sun, M., Zhang, Y. P., Guo, Y. X., Chua, K. M., & Wai, L. L. (2009). Integration of grid array antenna in chip package for highly integrated 60-GHz radios. *IEEE Antennas And Wireless Propagation Letters*, 8, 1364-1366.

<https://hdl.handle.net/10356/91622>

<https://doi.org/10.1109/LAWP.2009.2039031>

© 2009 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE. This material is presented to ensure timely dissemination of scholarly and technical work. Copyright and all rights therein are retained by authors or by other copyright holders. All persons copying this information are expected to adhere to the terms and constraints invoked by each author's copyright. In most cases, these works may not be reposted without the explicit permission of the copyright holder.

Downloaded on 26 Apr 2023 17:50:05 SGT

Integration of Grid Array Antenna in Chip Package for Highly Integrated 60-GHz Radios

Mei Sun, *Member, IEEE*, Y. P. Zhang, *Fellow, IEEE*, Y. X. Guo, *Senior Member, IEEE*, K. M. Chua, and L. L. Wai

Abstract—A grid array antenna integrated in a thin cavity-down ceramic ball grid array (CBGA) package in low-temperature cofired ceramic (LTCC) technology is reported. The grid array antenna, intended for use in highly integrated 60-GHz radios, has achieved good matching ($|S_{11}| \leq -10$ dB) and directional patterns from 57 to 64 GHz as well as high gain with the peak value of 13.5 dBi at 60 GHz.

Index Terms—60-GHz radio, grid array antenna, grid array package, low-temperature cofired ceramic (LTCC).

I. INTRODUCTION

THE Antenna-in-Package (AiP) technology that integrates an antenna (or antennas) in a radio chip package has become a key technology for 60-GHz wireless communications [1]–[6]. However, as the current AiP designs use only one antenna element, the gain is not enough. It is therefore necessary to extend it to an array antenna to achieve higher gain. Microstrip patch array antennas designed for 60-GHz applications have been reported [7], [8]. To avoid the complicated feeding network associated with microstrip patch array antennas, a grid array antenna is adopted in our work [9]. We show in this letter that the microstrip grid array antenna is an excellent array antenna candidate for 60-GHz applications and is particularly suitable for fabrication in low-temperature cofired ceramic (LTCC).

II. INTEGRATION OF GRID ARRAY ANTENNA IN CHIP PACKAGE

Fig. 1 illustrates the integration of the microstrip grid array antenna into a ball grid array package in FERRO A6 LTCC ($\epsilon_r = 5.9$ and $\tan \delta = 0.002$). Note that the package features standard wire bonding and there are four cofired laminated ceramic layers for the package. The first ceramic layer

is 0.385 mm thick, the second ceramic layer is 0.285 mm thick with an opening 3.8×2 mm², the third layer is 0.21 mm thick with an opening 5×3.2 mm², and the fourth layer is 0.385 mm thick with an opening 5×3.8 mm². These openings form the three-tier cavity that can house the 60-GHz radio receiver die. There are also five metallic layers for the package. The top layer provides the metallization for grid array antenna, the first buried layer the metallization for the partly meshed antenna ground plane, the second buried layer the metallization for the antenna feeding traces and signal traces, the third buried layer the metallization for the signal traces, and the bottom exposed layer the metallization for the package ground plane and solder ball pads. The package has 58 input/outputs with a JEDEC standard solder ball pitch of 0.65 mm. Two dummy solder balls are attached to the two corners of the package, respectively, for an enhanced attachment on the system printed circuit board (PCB). The size of the whole package is $13.5 \times 8 \times 1.265$ mm³. The microstrip grid array radiator consists of 14 printed rectangular meshes. The mesh length and width are $l = 2.5$ mm $\approx \lambda_g$ and $w = 1.365$ mm $\approx \lambda_g/2$, respectively, where λ_g is the guided wavelength at 60 GHz. The microstrip line that forms the meshes is 0.15 mm wide and 0.01 mm thick.

Fig. 2 shows the zoom-in view of the antenna feeding network. It consists of such packaging elements as coplanar waveguide (CPW) feed line cascaded first with traces, and then vias in a GSG arrangement. It is known that the GSG arrangement not only minimizes potential electromagnetic interference, but also improves the feeding performance. The signal via is finally fed to the antenna through an aperture in the partly meshed antenna ground. The CPW feed line is designed to be 50 Ω with a pitch of 0.25 mm and a line width of 0.15 mm. The signal via, the aperture, and ground via have diameters of 0.1, 0.3, and 0.1 mm respectively. The meshed ground parameters are $s = 0.35$ mm and $g = 0.2$ mm.

The ball grid array package was fabricated with nine green types and gold metal in a panel size of 100×100 mm² by the LTCC Boutique Foundry in SIMTech on the Nanyang Technological University (NTU) campus in Singapore. The antenna function of the package was tested with a probe-based measurement setup at IBM Thomas J. Watson Research Center in New York. Fig. 3 illustrates the test fixture to hold the package for testing.

Fig. 4 shows the performance of the package antenna. The measured 10-dB impedance bandwidth covers 8.5 GHz from 55.7 to 64.2 GHz, although it slightly shifts down compared to the simulated bandwidth from 57 to 64.5 GHz. The maximum peak gain values in the main beam direction are 13.5 dBi at

Manuscript received November 02, 2009. First published December 22, 2009; current version published January 12, 2010. This work was supported by the National University of Singapore Young Investigator Award 2009.

M. Sun is with the Institute for Infocomm Research, Singapore 138623, Singapore (e-mail: msun@i2r.a-star.edu.sg).

Y. P. Zhang is with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore (e-mail: eypzhang@ntu.edu.sg).

Y. X. Guo is with the Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117576, Singapore (e-mail: eleguoyx@nus.edu.sg).

K. M. Chua and L. L. Wai are with the Singapore Institute of Manufacturing Technology, Singapore 638075, Singapore (e-mail: kmchua@SIMTech.a-star.edu.sg).

Color versions of one or more of the figures in this letter are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/LAWP.2009.2039031

Fig. 1. The views of the ball grid array package with the grid array antenna: (a) top view, (b) bottom view, and (c) explored views with meshed ground.

60 GHz in the measurement and 14 dBi at 61.5 GHz in the simulation. An estimated efficiency is $> 85\%$ over 57–64 GHz.

Fig. 5 shows the simulated and measured radiation patterns of the package antenna. They reveal that both xz - and yz -plane patterns have the main lobe of radiations in the boresight directions with small cross-polarization radiation components. It is

Fig. 2. The zoom-in view of the antenna feeding structure.

Fig. 3. Illustration of the package antenna on the fixture for testing: (a) top view and (b) bottom view.

Fig. 4. Simulated and measured performance of the package antenna with (a) magnitude of S_{11} and (b) peak gain and efficiency as a function of frequency.

also seen that the measured and simulated copolar patterns agree very well and both have small back radiations. The back radiations increase at 57 and 64 GHz. This explains why the peak gain decreases at these frequencies as shown in Fig. 4. It is also seen from the measurement and simulation that the sidelobes are more significant at 57 and 64 GHz than those at 60 GHz.

Fig. 5. Simulated (dash line) and measured (solid line) radiation patterns of the package antenna at 57, 60, and 64 GHz, respectively.

Fig. 5. (continued) Simulated (dash line) and measured (solid line) radiation patterns of the package antenna at 57, 60, and 64 GHz, respectively.

III. CONCLUSION

A novel grid array antenna has been integrated as a chip-scale package in LTCC for the highly integrated 60-GHz radios. It shows a measured 10-dB bandwidth from 55.7 to 64.2 GHz, a measured maximum gain of 13.5 dBi, and an estimated radiation efficiency of $>85\%$ over the bandwidth. The antenna achieves the good upward radiation patterns with small cross-polarization radiation components in both measurement and simulation. The novel design concept and sophisticated LTCC process have guaranteed excellent performance of our grid array antenna over the targeted 7-GHz bandwidth from 57 to 64 GHz.

ACKNOWLEDGMENT

The authors would like to thank Dr. D. Liu of the IBM Thomas J. Watson Research Center for his help in testing the design.

REFERENCES

- [1] Y. P. Zhang, "Antenna-in-package (AiP) technology for modern radio systems," in *Proc. IEEE Workshop Antenna Technol.*, New York, Mar. 6–8, 2006, pp. 37–40.
- [2] Y. P. Zhang, M. Sun, K. M. Chua, L. L. Wai, D. Liu, and B. Gaucher, "Antenna-in-package in LTCC for 60-GHz radio," in *Proc. IEEE Workshop Antenna Technol.*, Cambridge, U.K., Mar. 1–3, 2007, pp. 279–282.
- [3] Y. P. Zhang, M. Sun, K. M. Chua, L. L. Wai, and D. Liu, "Integration of slot antenna in LTCC package for 60-GHz radios," *Electron. Lett.*, vol. 44, no. 5, pp. 330–331, Mar. 2008.
- [4] M. Sun, Y. P. Zhang, K. M. Chua, L. L. Wai, D. Liu, and B. Gaucher, "Integration of Yagi antenna in LTCC package for differential 60-GHz radio," *IEEE Trans. Antennas Propag.*, vol. 56, no. 8, pp. 2780–2783, Aug. 2008.
- [5] Y. P. Zhang, M. Sun, K. M. Chua, L. L. Wai, and D. Liu, "Antenna-in-package design for wirebond interconnection to highly-integrated 60-GHz radios," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 2842–2852, Oct. 2009.
- [6] Y. P. Zhang and D. Liu, "Antenna-on-chip and antenna-in-package solutions to millimeter-wave devices for wireless communication," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 2830–2841, Oct. 2009.
- [7] D. Liu and R. Sirdeshmukh, "A patch array antenna for 60 GHz package applications," in *Proc. IEEE Antenna Propag. Symp.*, Honolulu, HI, Jun. 10–15, 2008, pp. 1008–1011.
- [8] A. E. I. Lamminen, J. Säily, and A. R. Vimpri, "60 GHz patch antennas and arrays on LTCC with embedded-cavity substrates," *IEEE Trans. Antennas Propag.*, vol. 56, no. 9, pp. 2865–2874, Sep. 2008.
- [9] J. D. Kraus, "A backward angle-fire array antenna," *IEEE Trans. Antennas Propag.*, vol. 12, no. 1, pp. 48–50, Jan. 1964.