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Design and Integration of 60-GHz Grid Array Antenna in Chip Package

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Introduction

Driven by the great potential to revolutionize short-range high-speed wireless personal area network systems, designs towards low-cost highly-integrated 60-GHz radios in silicon semiconductor technology have received great attention in recent years. To provide 60-GHz radio chipsets with low-cost packaging and antenna solutions, the Antenna-in-Package (AiP) designs have shown promising results [1-3]. 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 and slot array antennas designed for 60-GHz applications has been reported. However, they suffer from the complex feeding network, sophisticated process techniques to achieve enhanced performance. To avoid these problems, the grid array antenna was adopted in our work [4]. We show that a grid array antenna is an excellent array antenna candidate for 60-GHz applications and is particularly suitable for fabrication in LTCC or integration in packages [5-6].

Design and Integration of 60-GHz Grid Array Antenna

A. Specifications for 60-GHz antennas

The specifications for antennas are defined according to the government regulations for unlicensed use, IEEE 802.15.3c standard and its usage model in the 60-GHz band [7]. Considering tolerances and variations in implementations, the targeted bandwidths of 60-GHz antennas can be simply defined as 3, 5, 7, and 9 GHz, respectively. Depending on the application, generally the main lobe of radiation of a 60-GHz antenna can be designed as one of the three: in a boresight, or angle-fire, or end-fire direction. The efficiency of 60-GHz antennas should be as high as possible. The gain of 60-GHz antennas is not specified although the maximum gain is limited by some regulations. As shown in TABLE I we derive the necessary combined gain values of transmit and receive antennas from a link budget analysis for 60-GHz antennas in indoor environment with a line-of-sight (LOS) path [7]. Here, we design a 60-GHz grid array antennas in LTCC technology for the first time with the maximum gain of ≥ 15 dBi, the impedance and radiation bandwidth of 7 GHz, and the efficiency of $\geq 80\%$. The ceramic used is A6-S from Ferro (dielectric constant 5.9 and loss tangent 0.0015) and metallic paste is silver or gold with good conductivity. The design was conducted in HFSS.

B. Study of un-integrated grid array antenna

The grid array antenna as shown in Fig. 1 consists of rectangular meshes of microstrip lines on a dielectric substrate backed by a metallic ground plane. It is fed by a metal via through an aperture on the ground plane. With the sides of the meshes l one wavelength by w a half-wavelength in the dielectric, the instantaneous currents are out of phase on the long sides of the meshes and in phase on the short sides of the meshes, respectively. Thus, the long sides of the meshes behave essentially as a feeding network and the short sides act as radiators producing the main lobe of radiation in the boresight direction [4]. Given the specified gain value of 15 dBi and considering the various losses, one can find the required number of meshes to be at least 14, which leads to an estimation of the length and width of the substrate as 11.5 mm by 5 mm, respectively. The thickness of the substrate h should be chosen to avoid

the excitation of the TE₁ mode surface wave. Finally, a body size of 13.5×8×0.375 mm³ is determined by also taking the LTCC layout rule into account. For low cost and easy fabrication, the width and thickness of the microstrip lines are kept uniform as 0.15 mm and 0.01 mm, respectively. The optimized mesh dimensions and the location of excitation v as well as the associated diameters of the metal via d_v and the aperture d_a on the ground plane are obtained as $l = 2.5 \text{ mm} \approx \lambda_g$, $w = 1.365 \text{ mm} \approx \lambda_g/2$, $d_v = 0.1 \text{ mm}$, $d_a = 0.3 \text{ mm}$, $x_v = 6.075 \text{ mm}$ and $y_v = 4 \text{ mm}$. Fig. 2 (a) shows a simulated bandwidth of 13 GHz from 51 to 64 GHz, Fig. 2 (b) and (c) show the antenna radiation patterns with a main lobe of radiation in the boresight direction, and Fig. 2 (d) shows a maximum peak realized gain of 15 dBi. The simulated radiation efficiency is better than 90% over the 7-GHz bandwidth.

C. Integration of grid array antenna in chip package

Fig. 3 illustrates the integration of the grid array antenna in a ball grid array package. Note that the package features standard wire bonding and there are four cofired laminated ceramic layers for the package. The 1st ceramic layer is 0.385 mm thick, the 2nd ceramic layer is 0.285 mm thick with an opening 3.8×2 mm², the 3rd layer is 0.21 mm thick with an opening 5×3.2 mm², and the 4th 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 1st buried layer the metallization for the partly meshed antenna ground plane, the 2nd buried layer the metallization for the antenna feeding traces and signal traces, the 3rd 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 PCB. The size of the whole package is 13.5×8×1.265 mm³. Fig. 3 (b) shows the AiP 3-D views with a quarter dollar as a size reference. Fig. 3 (c) 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 mm, 0.3 mm, and 0.1 mm respectively.

Fig. 4 (a) shows that the return loss values are higher than 10 dB from 57 to 64 GHz indicating a good matching to a 50-Ω source at these frequencies. Fig. 4 (b) and (c) show that the grid array antenna radiates a broadside beam with a low cross-polarization component. The simulated peak realized gain values are 12±2.5 dBi over the targeted 7-GHz bandwidth with an estimated radiation efficiency of better than 90% as shown in Fig. 4 (d).

Conclusion

A novel grid array antenna has been designed and further integrated as a chip-scale package in LTCC for the highly-integrated 60-GHz radios. The novel design concept and sophisticated LTCC process have guaranteed excellent performance of the grid array antenna over the targeted 7-GHz bandwidth from 57 to 67 GHz with a maximum gain of 14.5 dBi and an estimated radiation efficiency better than 90%. The antenna is being fabricated with 9 green types and gold metal in a panel size of 100×100 mm² by the LTCC Boutique Foundry in SIMTech on the NTU campus. The antenna function of the package will be tested with a

probe-based measurement setup at IBM Thomas J. Watson Research Center, USA. The verified results will be presented in the APMC conference.

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TABLE I
THE COMBINED ANTENNA GAIN REQUIRED FOR LOS PATH

Distance (m)	QPSK (2 Gbps)	16-QAM (4 Gbps)	64-QAM (6 Gbps)
1	13	19	24
5	27	33	38
10	33	39	44
20	39	45	50

Fig. 1. The grid array antenna: (a) top view and (b) bottom view.

Fig. 2. Simulated grid array antenna performance: (a) return loss, (b) xz plane & (c) yz plane radiation patterns at 60 GHz, and (d) peak realized gain.

Fig. 3. Ball grid array package with the grid array antenna: (a) exploded view with coordinates, (b) 3-D views with a quarter dollar as a size reference, and (c) zoom-in view of the antenna feeding structure.

Fig. 4. Simulated AiP performance: (a) return loss, (b) xz plane & (c) yz plane radiation patterns at 60 GHz, and (d) peak realized gain and efficiency.