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Advanced Wafer Level PKG solutions for 60GHz WiGig (802.11ad) Telecom Infrastructure

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Abstract

The continued growth in mobile data traffic is pushing for new and innovative solutions. Over the next few years, cellular phones, tablets, and computers will switch to 5G wireless technology. In this work, an highly integrated WiGig/802.11ad compliant 16+16 beam forming transceiver RFIC with advanced FOWLP (fan out wafer level packaging) technology known as eWLB (embedded wafer level BGA) is presented, which supports the need for the increased demand of data traffic. The 0.5mm pitch eWLB package measures 12.6x12.6x0.8mm and is using advanced dielectric materials and 2 metal layers for the redistribution layers (RDL). Full-wave electromagnetic simulations were performed including models of the chip layout, interconnects on the RDL, transitions and PCB. JEDEC level reliability was tested for component level reliability including MSL, TC, uHAST and HTS. The measurement results of compressed output power and noise figure for both bare die and packaged chip are presented.

Keywords-component; eWLB, FOWLP, 60Ghz mmWave, 5G, Telecom Infra, beam forming tranceiver, component level reliability, mmWave electrical simulation and characterization.

I. INTRODUCTION

60GHz (mmWave) Communication

In recent years millimeter wave systems have started to gain traction in the communications area due to advances in process technologies and integration solutions allowing for more cost effective products[1]. Today millimeter wave technology is used extensively in point-to-point communications in backhaul applications [1], as an alternative to running optical fiber. Millimeter wave outdoor fixed point-to-point radio links can allow for a low installation cost compared to optical fiber installations, whilst still allowing for a high capacity. Millimeter waves will be a part of the next generation cellular standard, 5G. The 60 GHz band is as of today used in communication for both backhaul applications, as well as WLAN applications. The IEEE 802.11ad WLAN communication standard uses the 60 GHz band[2]. The focus of future applications is often in the access network, providing connectivity to the end user devices such as smartphones and laptops. This is made possible due to the decrease in cost[3]. Most modern access network communication systems such as LTE or Wi-Fi utilize sub 6 GHz frequencies. There are several important differences between sub 6 GHz systems and millimeter wave systems. One difference is the physical size of the actual components. The size of an antenna is related to the wavelength. The fact that antennas in general are very small for 60 GHz systems allows for much more compact receiver and transmitter systems. At sub 6 GHz bands, a few hundred megahertz of unlicensed spectrum is available in most regions of the world, however at around 60 GHz several gigahertz of unlicensed spectrum is available. This gives the possibility of a very high throughput since the capacity is proportional to the available spectrum for high values of signal-to-noise ratio [4]

mmWave for 5G – FWA[5]

The total number of units that have one antenna or multiple RF transceivers, will in 2021 be 5.9 million and in 2028 60 million. Of which in 2021, the total of 15% are “base stations” [6]. The traditional macro bas station (BTS) will only cover 0.8% of the total market, while remote radio heads (RRH) cover 10% and small cells 3.6%. The main bulk will be CPEs with a market share of 85% (Customer Premises Equipment). A similar distribution is estimated for 2028.

This means that approximately 85% of the total number of RF modules that will be sold for the 5G mmWave market will be located in indoor or outdoor CPEs.

A 5G system includes multiple sub-systems which should be optimized and operate together. The RF subsystem transfers the radio signal all the way from the baseband signal (from the modem) into the air. How the RF solution is architected is very dependent on the use case and what you like to achieve, e.g. if you want to reach 150 meters or 1000 meters. There are four parts that sums up the total effective isotropic radiated power (EIRP) in an RF system (i.e the total “power” or “signal strength”):

- The RF power amplifier itself, i.e. its output power and linearity performance

- The number of power amplifiers tiled together in the antenna array
- The gain achieved from the antenna. For a given frequency, the antenna's effective area is proportional to the power gain, i.e. the size of the antenna is the main driver of the total gain that the antenna can achieve [7]
- Losses in the substrate, wave guides and packages

5G mmWave FWA infrastructure will be built mostly on small cells/RRHs connecting to CPEs. The main RF component volume will be on the CPE side which is close to 90% of all units sold. Using outdoor CPEs will probably be the most environmental friendly and the most cost-effective solution and the best fit for mmWave solutions, which is mainly a line of sight technology. According to Samsung[8], the size of the 5G system will be important, hence by bringing highly integrated 60 GHz technology to mmWave 5G, it would offer low cost, lower power consumption and the right size and solution to 5G marketplace.

II. TECHNOLOGY

Emerging WLCSP market of mmWave Applications

Market trends as experienced by end applications drive the emergence and evolution of any package technology. Currently, the primary automotive packaging solution is leaded or laminate wirebonding which account for more than 80% of the total assembly market.

The smallest possible package size is the Wafer Level Chip Scale Package (WLCSP), since the final package is no larger than the required circuit area. Since its introduction, WLCSP has experienced significant growth due to the small form factor, lower cost and high performance requirements of mobile and portable applications.

For RF and high-frequency applications, advanced wafer level packaging, eWLB (embedded wafer level BGA) showed less parasitic electrical interference, therefore, significantly improving overall device electrical performance. In one example, a 77GHz SiGe mixer packaged with eWLB achieved excellent high-frequency electrical performance due to the small contact dimensions and short signal pathways or interconnection length, which decreased parasitic effects [9,10].

The list below demonstrates the advantages of eWLB packaging solution for the mmWave device or high-frequency applications as compared to substrate or laminate-based packaging, such as flipchip or wirebonding.

1. **Interconnection length**: eWLB enables integration where the distance has to be as short as possible (loss increases with distance) to minimize loss (assuming both technologies have the same material loss).
2. **Conductance loss**: Plated Cu in organic substrate materials have large surface roughness because of the process used to improve adhesion and plating process control. eWLB uses a thin-film fab process for seed-layer and a well-controlled Cu plating to achieve a smooth Cu RDL surface which is more effective for skin effect in high-frequency ranges (At 100GHz, Cu skin depth is ~0.2µm).
3. **Dielectric loss**: Organic substrate materials have high losses in mm-Wave range and also heterogeneous material sets bring complexity in terms of electrical behaviors. eWLB uses molding compound and low-loss dielectric materials enabling achievement of less dielectric loss.
4. **Design flexibility**: eWLB provides more design flexibility for less routing interference with fine line width (LW) and line spacing (LS) capability (less than 10/10um LW/LS).

Traditionally, bare die technology is used where the die is attached with adhesive to the printed circuit board (PCB) and electrical contact is performed by wire bonding on the board. This challenging assembly has to endure several critical process steps: from bare die handling to shaping wire bonds in a way that RF requirements are met.

One key element for the change from a rather complex and expensive solution to an easy-to-use and, therefore, inexpensive and affordable product is the use of standard surface mount device (SMD) packaging technology. The eWLB package is SMD attached thereby simplifying the upstream assembly process and has already been proven in a few mmWave applications.

III. EXPERIMENTAL RESULTS

A. 60GHz WiGig eWLB assembly

eWLB package was designed in 12.6x12.6mm with 2-L RDL design utilizing low temperature curable advanced dielectric materials (ADM), which provide robust package reliability [11]. ADM is low temperature curable dielectric materials in eWLB process and it would be good for thermos-sensitive devices (embedded memory etc.) and less stress on the device with lower thermal budget.

As device performance is increased with high frequency, there is needs of multi-layer RDL for design flexibility in package level for system integration.

The specification details of each test vehicle are shown below in Table 1.

Table 1. Device specification of 60GHz eWLB.

Item	Description
PKG Type	eWLB FOWLP
PKG size	12.6x12.6mm
Lead count	314
Solder ball pitch	0.5mm
Ball size	0.30mm
Die Size	5.0x5.0mm
RDL Layer	2L
Fab node	SiGe
Die Thickness	0.40mm
PKG height	0.82mm
UBM	With UBM

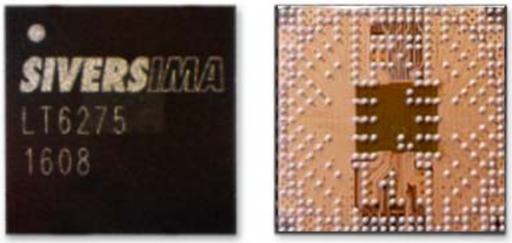

Figure 1. Beamforming transceiver for 60GHz WiGig applications.

B. *Component Level Reliability*

eWLB test vehicles were assembled and prepared for component level reliability tests according to Table 1 spec. Table 2 shows the package level reliability test conditions in this study. eWLB test vehicles is currently on-going with JEDEC standard package level reliability tests of MSL1, Temperature cycle (TC), high temperature storage life (HTS) and un-biased temperature humidity storage (uHAST).

Table 2. Package Level Reliability Results of eWLB with advanced dielectric materials (ADM).

Test	Test Condition	Test Conditions
Pre-Cond	JEDEC J-STD-020	MSL1
TC Temp. Cycling	JESD22-A104	Ta = -55/+125°C 1000 cycles
HTSL, High Temp. Storage Life	JESD22-A103	Ta=150°C 1000h
uHAST (w/o bias) after Precon	JESD22-A101	Ta=130°C, 85%RH 192h without bias

C. *Electrical Performance and Characterization*

The RF transitions in the package was designed in a 3D electromagnetic simulation software. This includes the chip-pad to RDL transition, the CPW type transmission-line structure within the package and the package to board transition. The RF design was first drafted in the three steps mentioned and then the complete chain, from microstrip on chip to microstrip on PCB was simulated for one channel. Finally the complete RF layout of the package was imported to the simulation software and a verification simulation with all paths and their interactions were performed. A picture of the RDL to PCB transition model can be seen in Fig. 2. The simulated package loss is approximately 2 dB over the band of operation.

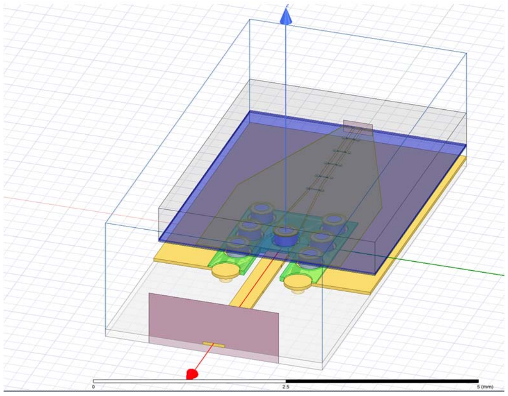

Figure 2. Sub-set of the 3D package model including coplanar waveguide (CPW) port, transition from package to PCB and microstrip on the PCB

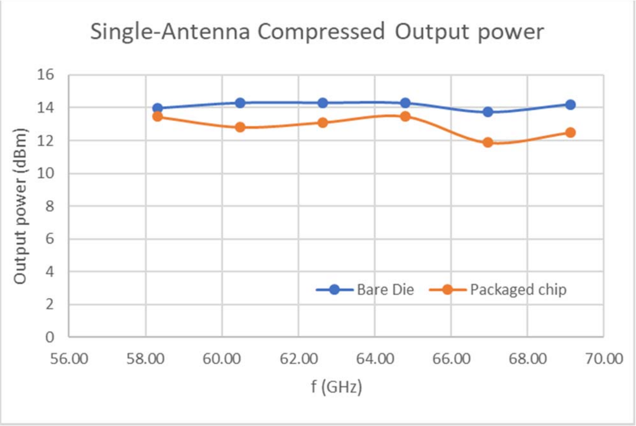

Figure 3. Comparison of single-antenna compressed output power between bare die and packaged chip

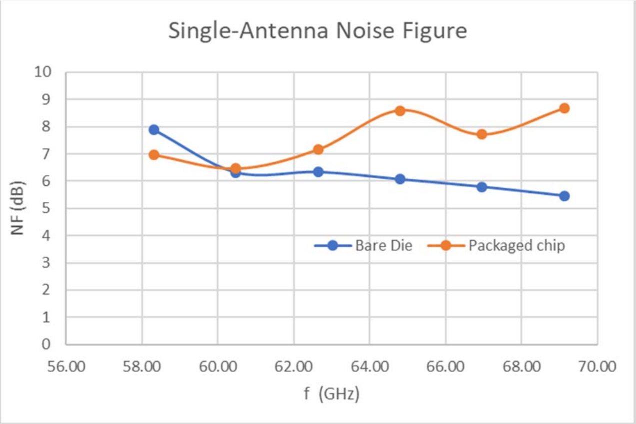

Figure 4. Comparison of single-antenna noise figure between bare die and packaged chip

To evaluate the performance of eWLB package, the compressed output power and noise figure of one single-antenna element is measured at the center frequency of each WiGig (802.11ad) channel for both bare die and package chip at board level with probe, as shown in Fig. 3 and 4. The difference in output power between bare die and packaged chip represents the actual loss of eWLB package including the PCB transition. Due to different source and load impedances when the bare die is probed compared to when it is packaged the difference shown in the figures varies slightly.

IV. CONCLUSION

60GHz beamforming transceiver eWLB was assembled and characterized for its reliability and electrical performance of eWLB FOWLP with 0.5mm ball pitch and 2-L RDL of ADM.

1. eWLB test vehicles passed JEDEC standard reliability tests, MSL-1, TC, HTS, uHAST with 2-L RDL structure.
2. Simulation of the complete RF transitions in the package for one channel shows 2dB loss over the WiGig (802.11ad) band. The compressed output power and noise figure for both bare die and packaged chip are measured and compared.

Furthermore, factors such as superior high frequency electrical performance and the ability to enable heterogeneous integration such as the integration of Antenna, ie. AiP (Antenna-in-Package). into the various thin-film layers, active/passive devices into the mold compound or encapsulation, and achieve 3D vertical interconnections for new 3D SiP and 2.5D/3D packaging solutions, differentiate eWLB from other packaging technologies. eWLB technology provides a more holistic performance relevant to an increasingly broad range of emerging applications including 5G mmWave applications with AiP.

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