Advances in High Frequency Packaging

April 2019
Motivation

• Expected global mobile data usage to grow from 11.2 (back in 2017) to 48.3 Petabytes/month (in 2021)
• Rethinking of mobile data access is required and 5G has emerged as a strong proposal to achieve a 1000X increase in mobile data capacity connecting 7 billion people and 7 trillion devices required to be energy efficient and almost zero downtime
• 5G is aiming to employ phased arrays as a mean to direct beams in specific directions and this is necessary because backhaul and access links will share the same air channel, so all network elements (BS, Aps, Ues) will inevitably require directional, steerable antennas for spatial aggregation
Motivation

• Active Electronically Scan Array (AESA) constitute a kind of phased array architecture where there is a T/R module per antenna element
• Those T/R modules will eventually require some sort of packaging and this is going to be challenging because of the space constraints imposed by the “Lattice Spacing” which determines among others, the maximum beam steering angle or “field of view”
• Lattice spacing sets the packaging density in the array, influencing mainly the cross-coupling between circuits and thermal dissipation properties of the assembly
Molded vs Air-Cavity Packaging

**MOLDED PACKAGE**
- Mold Compound
- Die
- Gold Wire
- Leadframe
- Silver Epoxy
- Die Pad

**AIR CAVITY PACKAGE**
- Plastic/Ceramic Lid
- Gold Wire
- AIR CAVITY
- B-Stage Epoxy
- Vias

- Very mature technology
- Very low cost
- High losses, high parasitics
- Not suitable for packaging ICs with air bridges
- Not suitable for mmWave applications

- Mature technology
- Higher cost
- Lower losses, lower parasitics
- Suitable for packaging ICs with air bridges
- Suitable for mmWave applications provided some modifications
Why is packaging at mmWaves so difficult?

• In general, a package design needs to address the following concerns no matter at what frequency is it intended to operate:
  • Material compatibility (wirebondability, solderability, laser ablation vs mechanical routing, substrate losses, etc)
  • Reliability
  • Interconnectivity (Wirebonding, flip-chip, etc)
  • Die attachment and lid/sealing methods (die handling employing collets, encapsulation, seam sealing, etc)
  • Hermiticity (or protection of internal circuits)
  • Thermal design
• On top of the above concerns, the following additional issues arise whenever dealing with mmWave packaging designs:
  • Distributed effects
  • Undesired resonances, parasitic effects and adequate RF grounding
  • Circuit traces that must be treated as TLs
  • Substrate dispersion effects
  • Coupling and cross-talk between circuit elements
Whenever the physical dimensions of circuit elements become a fraction of the wavelength, distributed effects become relevant in one of the following manners:

- Lumped elements namely resistors, capacitors and inductors no longer behave as such. Their impedance will vary over frequency in ways that no longer can be represented by a single passive component.
- Metal package housings would start to behave as cavity resonators.
- Interconnecting signal traces must be treated as transmission lines.
- Wirebonds need to be modeled as complex networks.
- As frequency increases, wirebonds will resonate or appear as antennas.
MCL’s LTCC Packages: Technology Roadmap

1st and 2nd Level Interconnects
- Ball - Stich
- Wedge –Wedge
- Reverse Bond
- V- Bond
- Ribbon Bond
- Flip Chip

Mat. Characterization
- Er and Tand up to mmWaves
- Dispersion (signal integrity)
- Anisotropy
- Power Handling/Thermal Resistance

Process and technology
- Photo-Imageable process
- Conductor’s surface roughness
- Contour definition
- Tightening of line widths and spacings
- Tightening of conductor’s dimensions tolerances
- New material systems

Multiphysics Modeling
- Circuital analysis and co-simulation
- Method of Moments
- Finite Element Method
- Time Domain Reflectometry
- Thermal Analysis
- Mechanical stress Analysis

Qual and test plans

LTCC Substrate
LTCC is naturally a packaging technology.
LTCC mmWave Packaging Solutions

Plastic lid over package

- Plastic lid
- IC
- LTCC Substrate
- Wire-bonds
LTCC mmWave Packaging Solution
LTCC mmWave Packaging Solution

KAT-2 LTCC Package (A3-02)

Attenuation (dB)

Frequency (MHz)

S11  S21  S22
Organic PCB mmWave Packaging Solutions

ISOMETRIC VIEW

Drop in die
Organic PCB mmWave Packaging Solutions

Package’s thru performance

**S11 - Direct WB**

- Direct WB
- Thru-line

**S21 - Direct WB**

- Direct WB (Normalized)
Organic PCB mmWave Packaging Solutions

Packaged KAT-2+ performance

KAT-2 Insertion Loss

S11 - KAT 2
Flip – Chip Packaging Solutions

SPDT Flip – Chip switch assembly

SPDT Die size:
2.495mm x 2.149mm

Package Dimensions:
3.0 x 3.0mm
SPDT Switch - Assembly

Test board*

RFC

RF1

Thru RF1

RF2

Thru RF2

*TLY-5, 5mil thick substrate

Open die on LTCC

IC

LTCC Substrate

PCB

Over-molding compound

Over-molded die on LTCC
SPDT Switch - Units measured

A0: Open die on LTCC B14-L2-P1A+
A1: Over Molded die on LTCC P/N B14-L2-P1A+
A2: Over Molded die on LTCC P/N B14-L2-P1A+
A3: Over Molded die on LTCC P/N B14-L2-P1A+
HFSS 1: Over Molded die dummy on LTCC B14-L2-P1A+ (assuming no underfill)
HFSS 2: Over Molded die dummy on LTCC B14-L2-P1A+ (assuming underfill)

Top View (No molding included)

No underfill: Target implementation (HFSS1 model)

Underfill: Most likely this may end up being the situation (HFSS2 model)
SPDT Switch – Measurements

Open die on LTCC (Tests Data) vs HFSS simulation

A0 (open die) and HFSS1 show good agreement. No die underfilling. No molding compound in A0 (open die).
SPDT Switch – Measurements

Over-molded die on LTCC (Tests Data) vs HFSS simulation

A1 (over-molded) and HFSS2 show good agreement. Suspected molding underfilling on fabricated unit.
SPDT Switch – Measurements

Open die on LTCC (Tests Data) vs Over-molded die on LTCC (Tests Data)

A0 (open die) has better performance than A1 (over-molded)
Case temperature: 53.8 ºC maximum.
Multiphysics Analysis: Stress Results

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**Details of Stress Probe**

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<th>Global Coordinate System</th>
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<td>Result Selection</td>
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References


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Your partners for success since 1968

Thank You