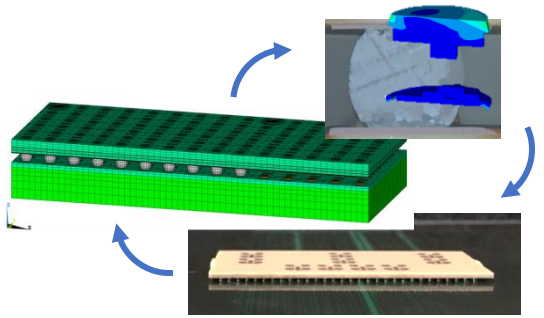
Finite Element Analysis of the Board Level Reliability of High Frequency Automotive Package Developments

IPCEI WIN-FDSOI
TF1 Energy Efficient Chips
Group C: 5G and Radar complete system showcases



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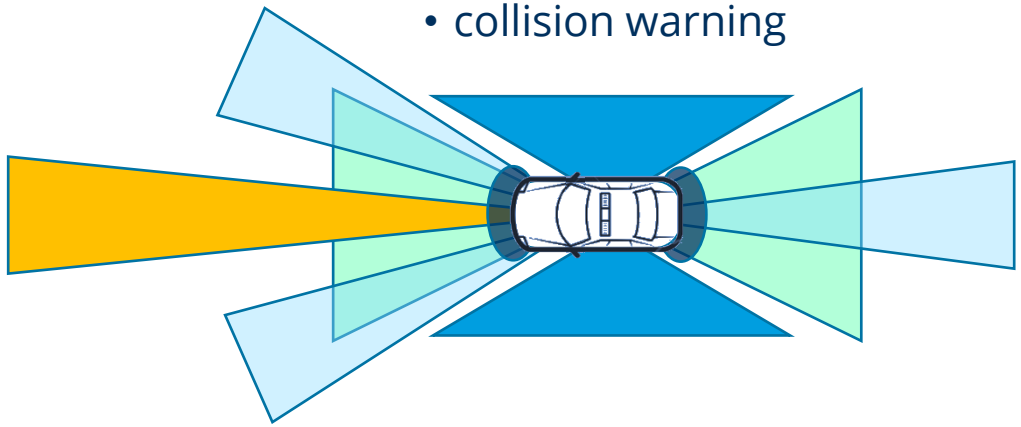
Motivation

- adaptive cruise control
- distance control

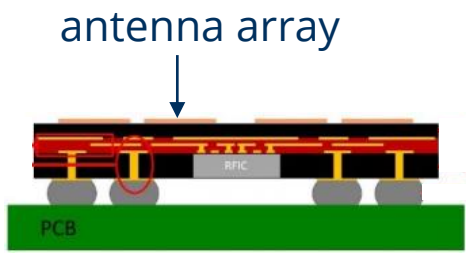
- blind spot detection
- collision warning



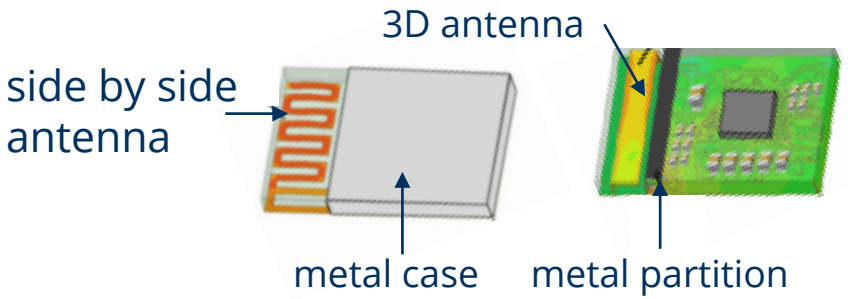
- object detection
- parking aid

- Research on development of package concepts and technologies for mmWave applications
- Package solutions aim for harsh environment conditions

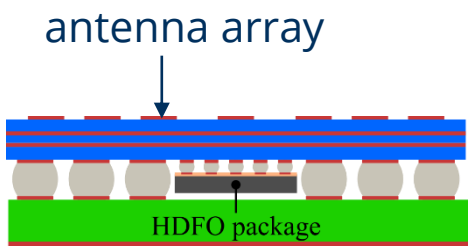
Motivation



Ref.: Wang, S. et al., Proceedings of EPTC, 2019.



Ref.: Tsai, M. et al., Proceedings of EPTC, 2019.



- Package developments involve materials specifically designed for low dielectric losses
- RF organic substrate materials compared to high-T_g materials provide:
  - Low dielectric coefficients (ε_r) and loss factor (tanδ)
  - Increased Young's moduli (E) and glass transition temperatures (T_g)
  - Decreased coefficients of thermal expansion (CTE)

  → Increased interconnect stresses have to be taken into account

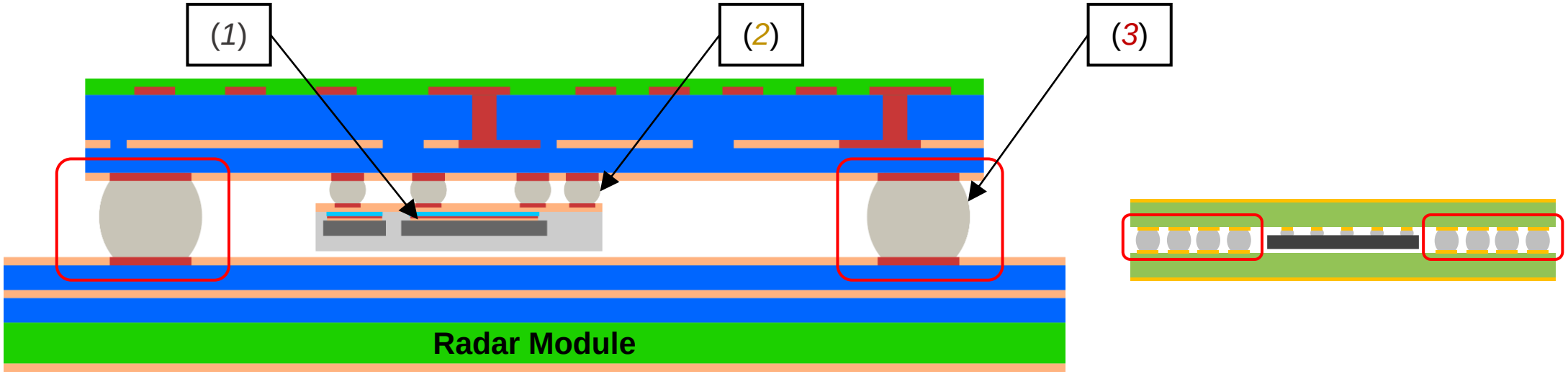
Outline

- FEM based Thermo-mechanical Modeling of Radar Packages
  - Material Data Research with Focus on RF Organic Substrates
  - Package Modeling for Board Level Reliability Analysis
  - Analysis of Module Build-up Influence on Package Behaviour

- Reliability and Failure Analysis of Radar Package Specimens
  - Development and Manufacturing of Radar Package Specimens
  - Reliability and Failure Analysis Results

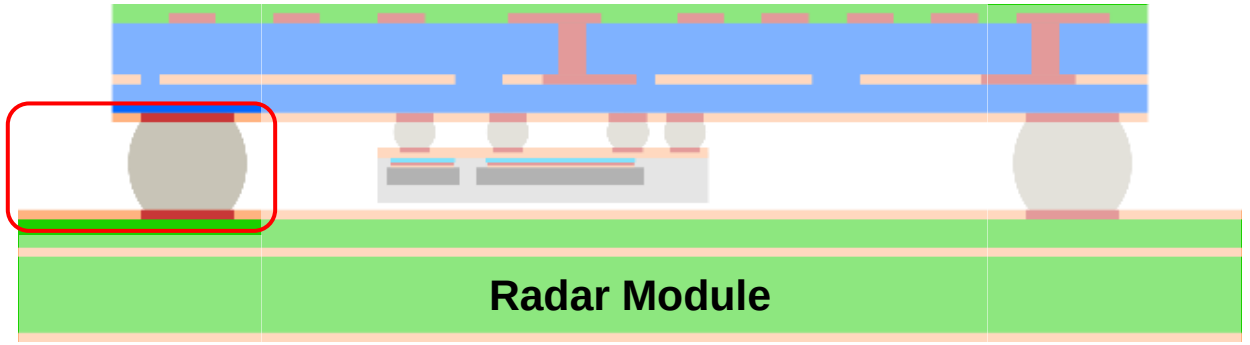
Radar Package Reliability

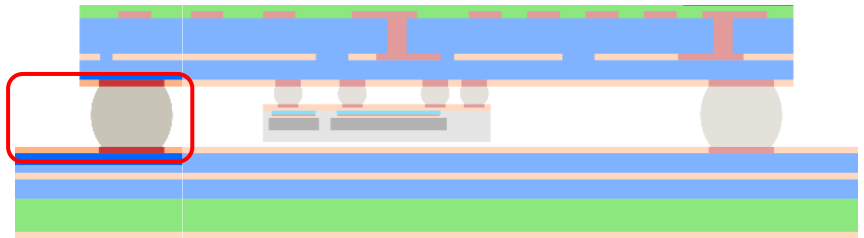
- Thermo-mechanical reliability can be analysed considering three main regions of interest
  - RF module package
  - RF module-to-antenna-board interconnects
  - antenna-to-system board interconnects



Radar Package Reliability

- Radar approach is following a land-side RF package concept
- Reliability assessment focuses on board level interconnects
- Reliability behaviour depends on
  - selected materials (EMC, substrate, solder alloy, …),
  - package geometry,
  - package stack-up (layer thickness, metal coverage, …),
  - and design features (shielding)

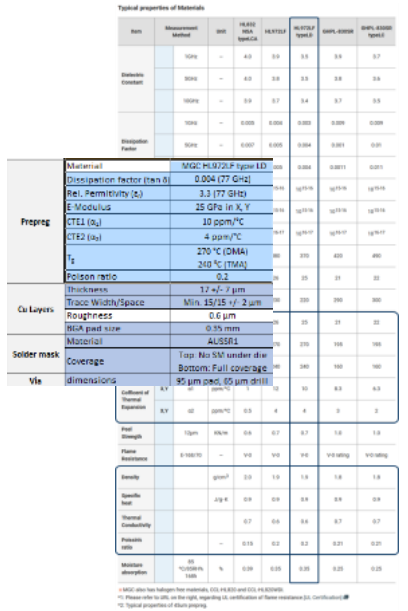


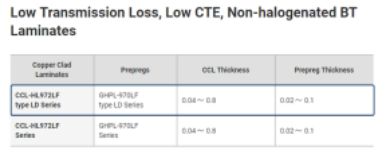


FEM – RF substrate study

- BLR is significantly effected by the thermo-mechanical substrate properties
- Current RF materials have been researched and selected for FEA and for specimen manufacturing considering availability

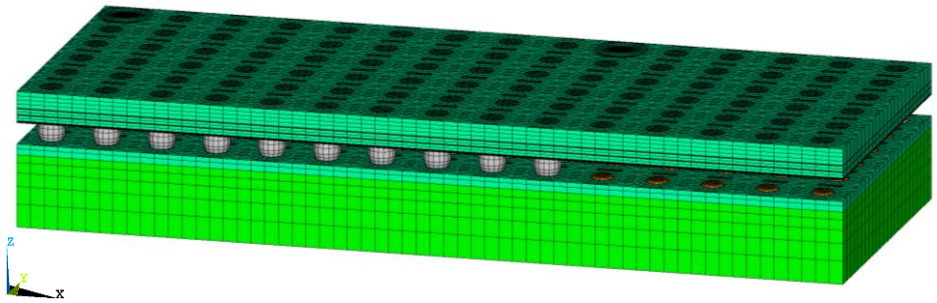
manufacturer	material	tanδ [-]	ε_r [-]	stiffness x/y [GPa]	poisson ratio [-]	CTE x/y/z [ppm/K]	T_g [°C]	thermal conductivity [W/(m·K)]
Panasonic	Megtron 6 R5775[A]	0.002-0.006[B]	3.40-3.71[B]	16.3/14.3	0.2	14-16/14-16/(45;260)[C]	185/210[D]	0.42
	Megtron 7 R5785	0.002-0.005[B]	3.37-3.6[B]	15.6/13.7		14-16/14-16/(42;280)[C]	200/210[D]	0.40
	R1515A	0.015	4.8	27/-[H]		12/12/(30;140)[C]	-/205[D]	
	R1515W	0.015	4.8	35/-[H]		9/9/(22;97)[C]	-/250[D]	
	R-G525T	0.015	4.3	19...20/-[H]		3-5/3-5/-	-/270[D]	
	R-G545L	0.0028-0.0037[I]	3.5	23/-		10/10/22	-/230[D]	
Rogers	3003	0.0010	3.00	0.93/0.82[E]		17/16/25	115[J]	0.50
	4835	0.0037	3.48	7.78/0.136[F]		10/12/31	>280	0.66
Isola	i-Tera	0.0031	3.45	21.1/19.2[B]	0.234/0.222[C]	12/12/(55;290)[A]	200	0.41
	TerraGreen	0.0039	3.44	21.5/18.9[B]	0.238/0.231[C]	16/16/-	200	0.32
	Astra	0.0017	3.00	18.6/17.4[B]	0.183/0.182[C]	12/12/(50-70;250-350)[A]	200	0.45
	Tachyon 100G	0.0021	3.02	17.6/16.7	0.165/0.156[C]	15/15/(45;250)[A]	200/220[D]	0.42
Mitsubishi	HL972LF type LD	0.004	3.3	25	0.2	10;4[A]	270/240[G]	0.6

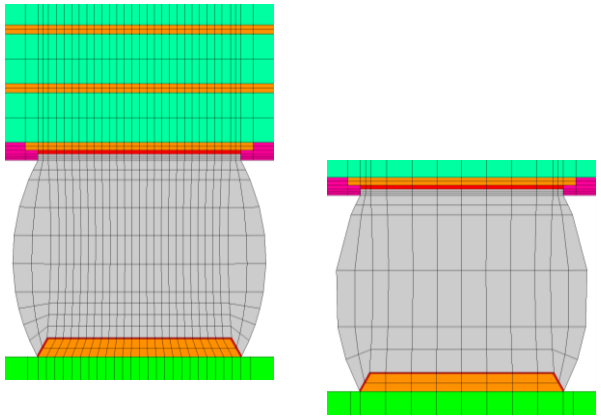


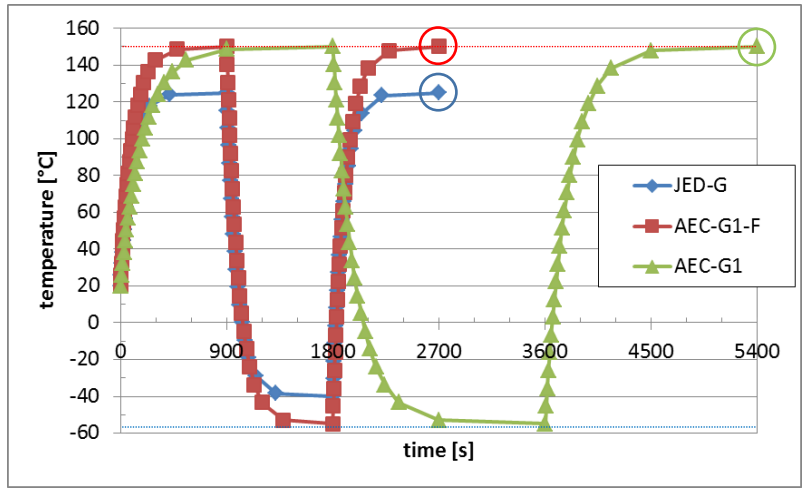


FEM - Package Modeling

- Parametric modeling to enable package design and material modifications and load profile considerations
- Simplifications implemented to increase calculation performance (e. g. ¼ symmetry)





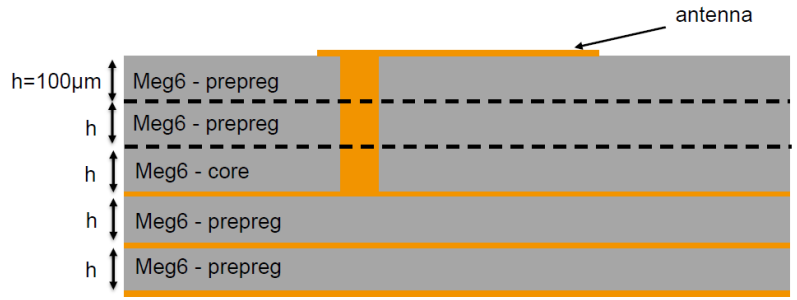


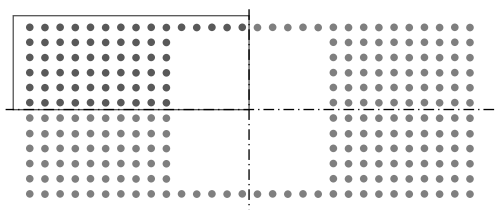
test standard	dwell temp's	cycles/hour
JEDEC A104E condition G	-40/125°C	2
AEC Q100 grade 1 fast	-55/150°C	
AEC Q100 grade 1		1

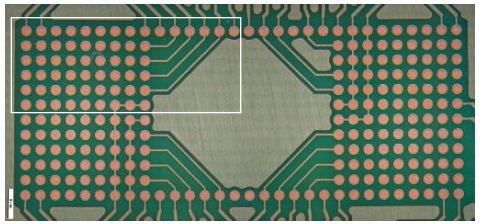
FEM - Radar Package Model

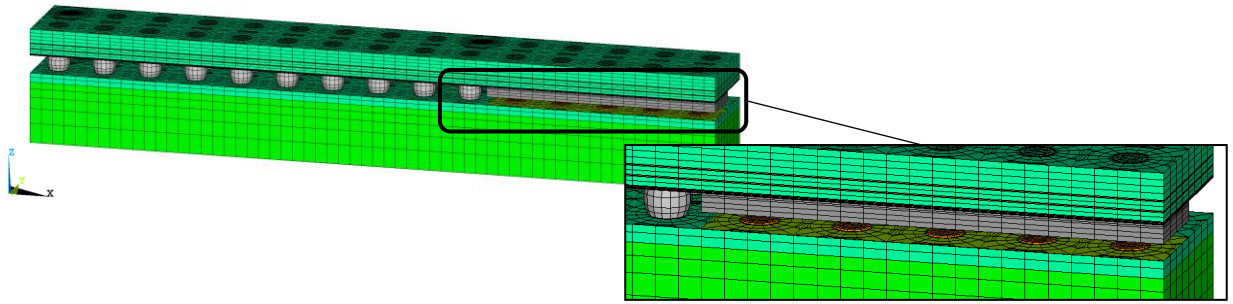
- FE model of the Radar package considering recent design spec's (geometry, materials)

design parameter	value
package outline	12 x 30 mm²
grid size (2x)	12 x 10 + 1 x 10
stand-off	0.4 mm
joint diameter	0.5 mm
pitch	1 mm
antenna board thickness / pad∅	0.5 mm / 0.45 mm
system board thickness / pad∅	1.5 mm / 0.40 mm
system board HF layer thickness	0.2 mm



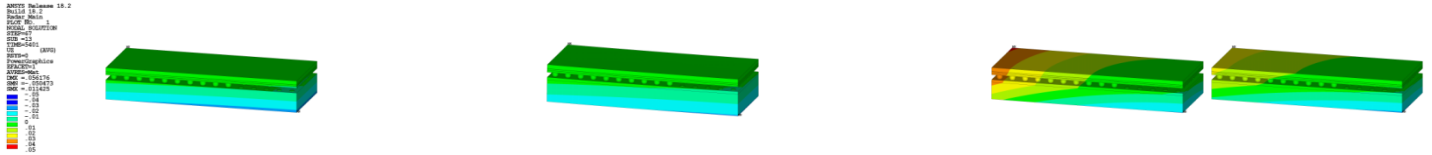


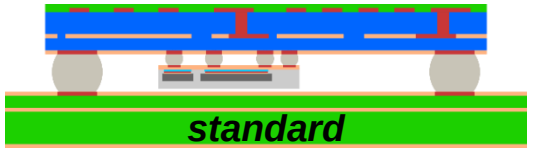


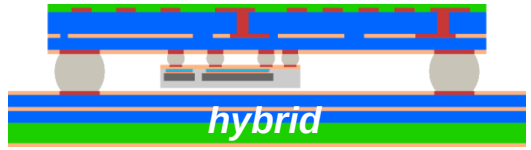


FEM - Package Deformation

- Analysis of a series of package material configurations

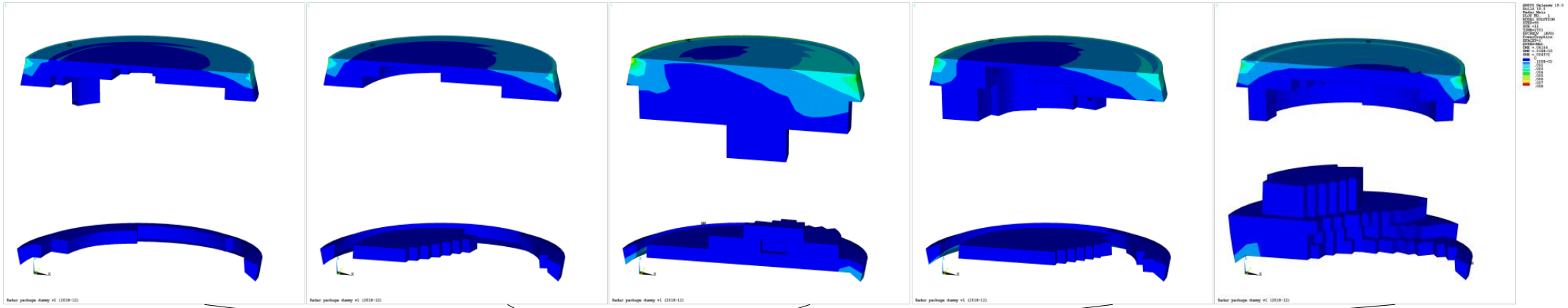
	standard	*hybrid*				
	Meg6		**Meg6**		**G545L**	**Astra**
TC	JESD		AEC-*f*	AEC	JESD	
antenna board	Meg6		Meg6		G545L	Astra
motherboard	FR4		Meg6		G545L	Astra
			FR4		FR4	FR4
						
u_{z_max}	8	9	11	11	42	27
relative [%]	-11	-	+22	+22	+367	+200
		reference				





FEM - Solder Joint Fatigue

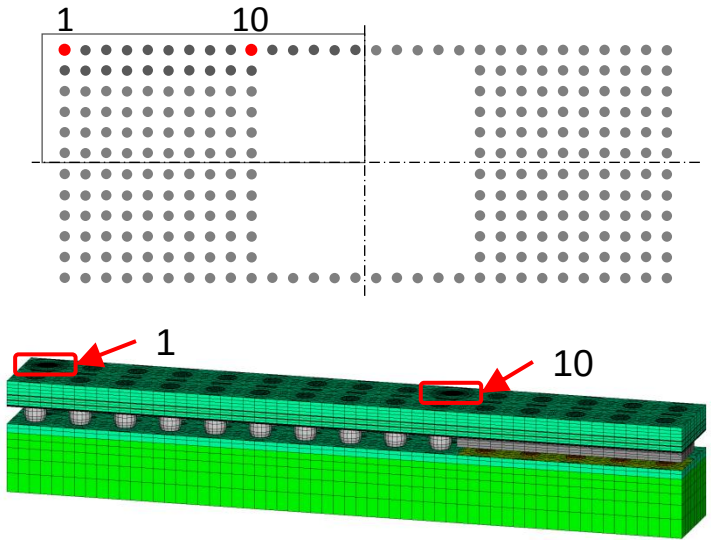
- Analysis of the accumulated creep strain per cycle $\Delta\varepsilon_{cr\_acc}$ at the outermost solder joint
- Evaluation of the accumulated creep strain of the critically strained solder joint volume
- G545 and HL972 show high strains and large compromised volume indicating shorter life
- HL972 shows indications for change of the damage location



	standard		*hybrid*		*standard*
	Meg6	**Meg6**	**G545**	**Astra**	**HL972LF**
$\Delta\varepsilon_{cr\_acc}$ **[%]**	-15	-	+126	+54	+37
		reference			

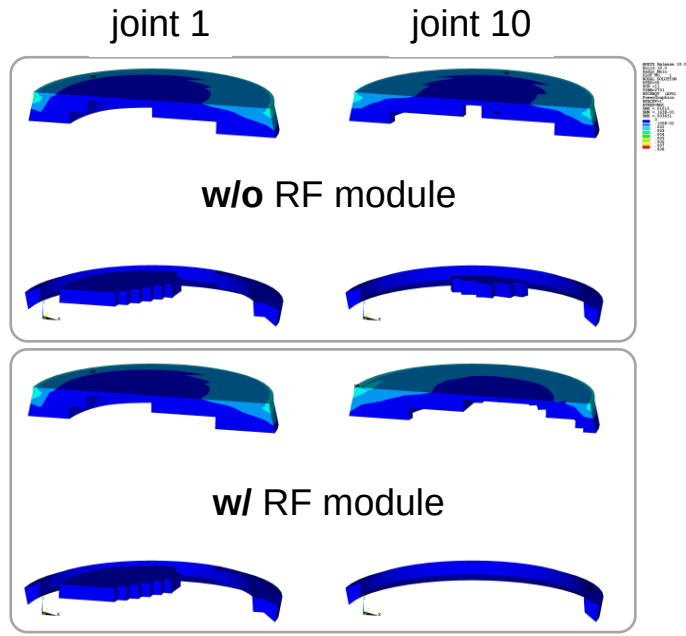
FEM - Solder Joint Fatigue

- Analysis of land-side RF package influence on solder joint loading (hybrid approach)
- $\Delta\varepsilon_{cr\_acc}$ of outermost solder joint and solder joint close to the RF package corner
- High stress near RF package, negligible difference in creep strain, minor change of compromised solder volume → need for update on RF package geometry & materials



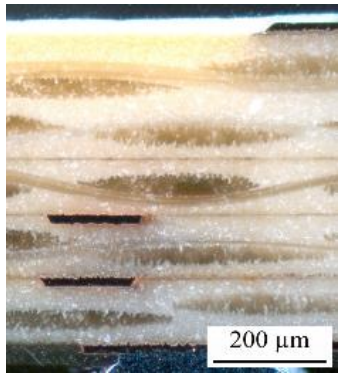
$\Delta\varepsilon_{cr\_acc}$ [%]	w/o RF module	w/ RF module
1 - outermost joint	-*	-1
10 - joint near RF module	1	-1

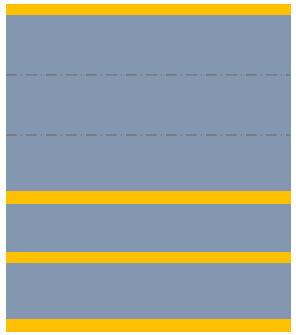
*reference



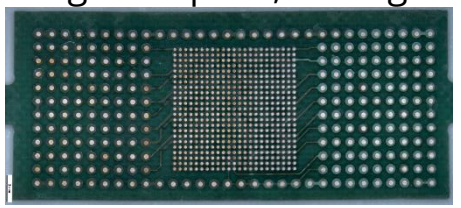
Specimen Manufacturing

- Antenna boards based on RF substrate material
  - Megtron6 (CTE_{xy} 15 ppm/K, T_{g_DSC} = 185 °C)
  - dimensions: 30 x 12 mm²
  - thickness stack up: 0.5 mm
  - 4ML: 18 µm copper
  - daisy chain, dummy RDL & antennas

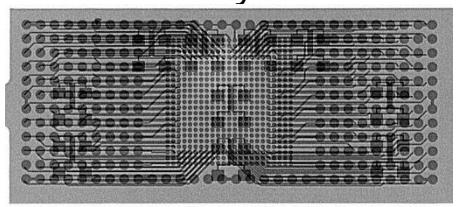




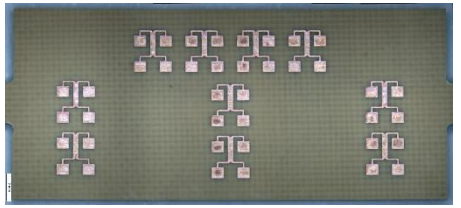
package footprint, balling area

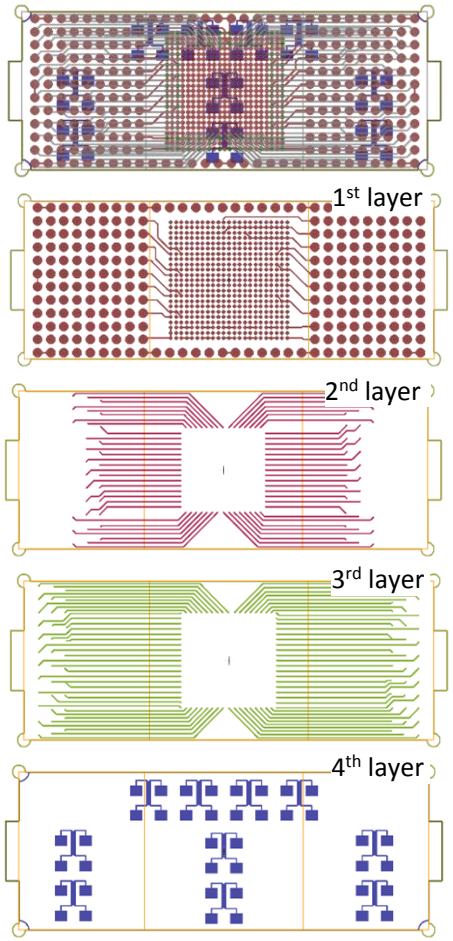


dummy RDL



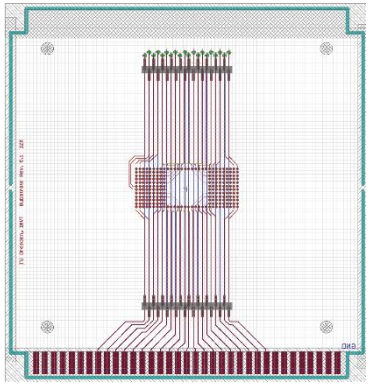
antenna structures

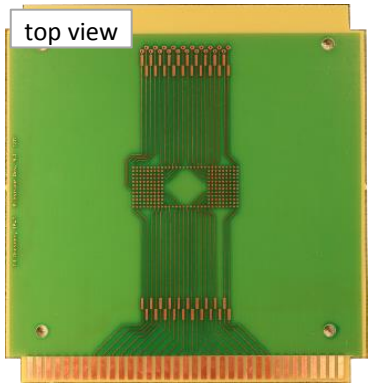


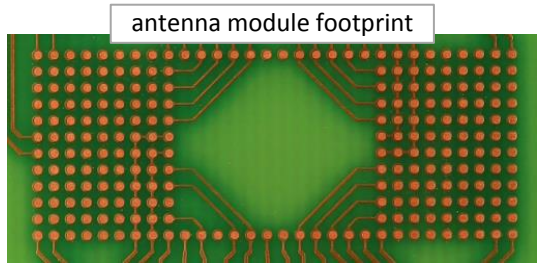


Module Assembly

- System boards based on high-T_g substrate materials
  - two materials A & B (CTE_{xy} 11 *vs.* 13 ppm/K, T_{g_DSC} = 180 °C)
  - dimensions: 100 x 105 mm²
  - thickness: 1.5 mm
  - 18 µm copper, SMD
  - daisy chain
- 500 µm solder balls (SAC305) for antenna-to-system board assembly
- No land side RF package



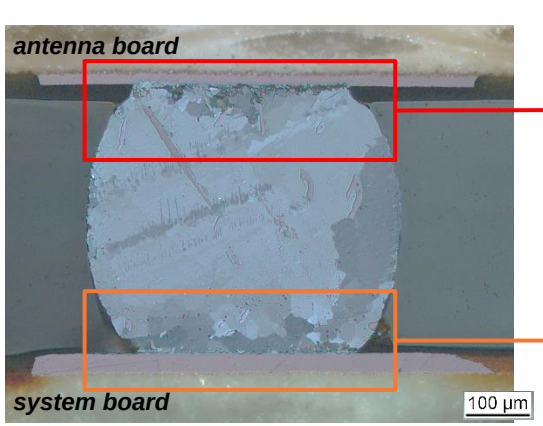




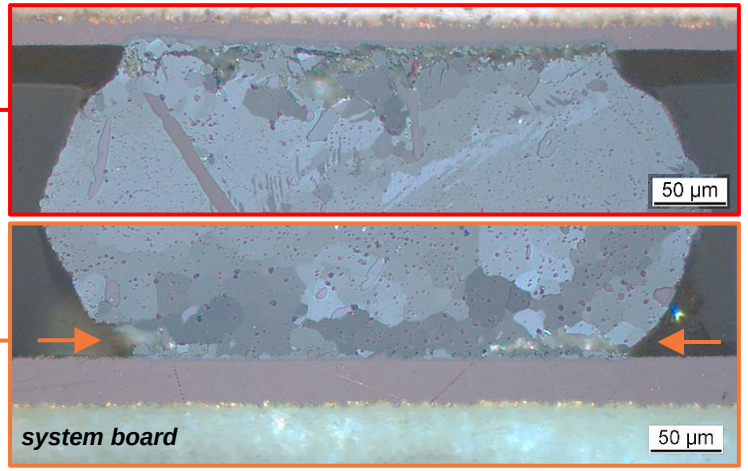
antenna-to-system board assembly

Board Reliability Testing

- 2 sets of Radar module assemblies
- AEC Q100 G1 TC -55/150°C, 1 cycle/h
- Up to 1,250 cycles accomplished
- No electrical fails for up to 1,000 cycles for material A samples
- Solder joints at module corners and close to RF package show failure indications after 500 (material B) and 1,250 cycles (material A) respectively
- PFA reveals solder fatigue:
- Good match to FEA findings



cross section after 750 cycles TCoB



crack propagation towards middle of solder joint

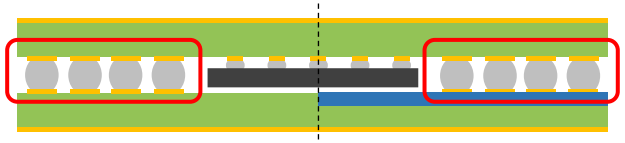
crack initialization and propagation on both edges of solder joint

Summary & Conclusions

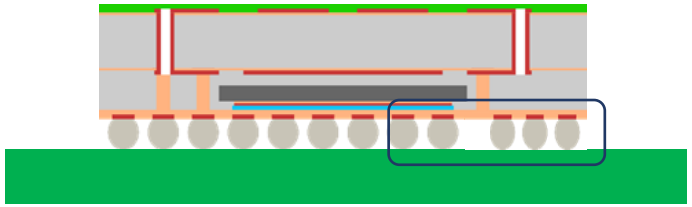
- Radar and other mmWave related package solutions demand for careful development with regard to electrical and thermo-mechanical performance
- FE simulation approach addressing the board level reliability of a Radar package with a land-side RF package developed
- Detailed material study on RF substrate materials conducted
- FEA results indicate solder fatigue as major failure risk - proven by PFA
- Radar module specimens manufactured and tested
- TCoB -55/150°C accomplished proving ability to meet AEC Q100 G1

Outlook

- Ongoing TCoB considering material and geometry variations



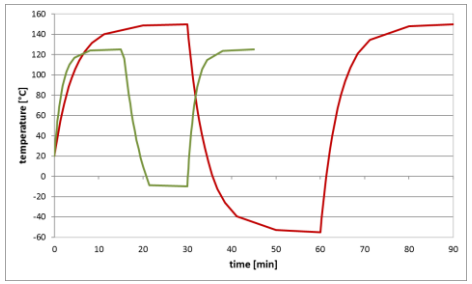
- 5G package FEA approach in development incl. multi-pitch considerations

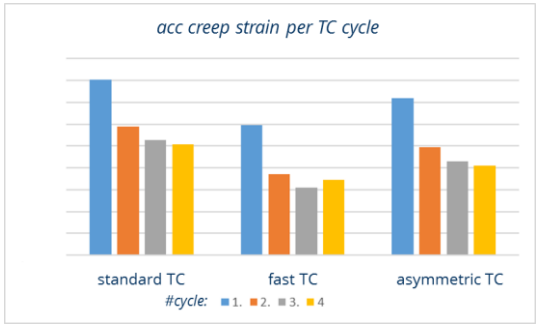


- Antenna module:
  overall package size: 10 mm x 10 mm
  mold thickness: 200 µm
- RF/logic module:
  overall package size: 10 mm x 10 mm
  mold thickness: 200 µm

package approach	module	solder ball diameter	solder ball pitch	solder ball pad size
5G (double mold)	RF/logic module to system board interconnect	250 µm	400 µm	200 µm

- FEA on TC profile in progress





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Thank you!

Comments, Questions?

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