Radar Devices, Challenges and Packaging Technology Solutions
FTF-SDS-F0023

Darrel Frear | Packaging Technology Development

APR. 2014
Session Introduction

• This presentation is an overview of the challenges and requirements of creating a robust package solution for automotive radar applications. Freescale has created a world-class solution for radar that meets electrical and reliability performance requirements. The importance of co-design of the radar package with the customer board design is highlighted.

• Presented by Darrel Frear, manager of Package Technology Development for Freescale
Session Objectives

• After completing this session you will be able to:
  - Understand the growing need for Automotive Radar
  - Understand the electrical and reliability performance of the Freescale package solution for automotive radar
  - Develop optimized radar board design to utilize the Freescale packaged radar solution
Sample Learning Objectives

• **By completing this training, you will be able to:**
  - Describe the growth of automotive radar
  - Understand how to design board solutions for automotive radar in customer applications
Agenda

• The need for automotive radar at 77GHz
  – Worldwide regulations and trends shaping the market
• Radar Package Requirements/Challenges
• Package Solution – Redistributed Chip Package (RCP)
• Radar Package Performance
• Session Review and Wrap-up
The Need Automotive Radar at 77GHz
Zero Fatalities as a Common Goal

- Electronic Component Growth Dynamics
  - New systems are introduced in high-end vehicles based on consumer demand for safety
  - Government safety regulations are changing to mandate new systems
  - Increasing safety legislation for safety systems (i.e., TPMS, ESC) is driving adoption
  - ADAS, radar and camera systems expected to be the next legislative mandate

Source: http://www.wolframalpha.com

<table>
<thead>
<tr>
<th></th>
<th>U.S. Mortality Results</th>
<th>World Mortality Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of deaths</strong></td>
<td>45,077 deaths per year</td>
<td>1.189 million deaths per year</td>
</tr>
<tr>
<td><strong>Cause of death probability</strong></td>
<td>1 in 54 ~ 1.9%</td>
<td>1 in 48 ~ 2.1%</td>
</tr>
<tr>
<td><strong>Rate of death</strong></td>
<td>15 deaths per 100,000 persons per year</td>
<td>19 deaths per 100,000 persons per year</td>
</tr>
<tr>
<td><strong>DALY</strong></td>
<td>1.243 million life years lost per year</td>
<td>38.68 million life years lost per year</td>
</tr>
</tbody>
</table>
Automotive Radar

Vehicle with active safety based on the millimeter-wave radar with auxiliary systems

Extended Collision Warning

Collision Warning

Lane Departure Warning

Rear Collision Warning and migration

Extended rear Collision Warning and blind-spot
Radar Applications

Sensor Technologies
for Driver Assistance Systems

LRR Radar (77 GHz)
SRR Radar (24 / 79 GHz)

<table>
<thead>
<tr>
<th>SRR</th>
<th>LRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking assist</td>
<td>ACC</td>
</tr>
<tr>
<td></td>
<td>ACC stop &amp; GO</td>
</tr>
<tr>
<td></td>
<td>Lane keeping support</td>
</tr>
<tr>
<td></td>
<td>Collision Warning</td>
</tr>
<tr>
<td></td>
<td>Pre-crash sensing /</td>
</tr>
<tr>
<td></td>
<td>pre-crash brake assist</td>
</tr>
<tr>
<td></td>
<td>Pre-crash collision</td>
</tr>
<tr>
<td></td>
<td>avoidance /</td>
</tr>
<tr>
<td></td>
<td>automatic emergency brake</td>
</tr>
</tbody>
</table>

Comfort Functions

Safety Functions

Vehicle Guidance
Freescale Radar Sensor Application Overview

1. Long Range Radar
   - Narrow-band operation
   - Covers distances up to 250 m
   - Vehicle speed up to 250 km/h
   - Narrow beam
   - Spatial resolution typically 0.5 m
   - Enables adaptive cruise control

2. Short Range Radar
   - Wide-band operation
   - Covers distances up to 30 m
   - Vehicle speed up to 150 km/h
   - Wide view
   - Monitors immediate car surrounding
Radar Key Trends & Implications

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Trend</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory</td>
<td>• Truck Mandate EU ‘14, JPN ‘13</td>
<td>• Drives ACC adoption</td>
</tr>
<tr>
<td></td>
<td>• Sunset on 24GHz EU ‘18, JPN ‘16</td>
<td>• Drives consolidation onto 76-81 GHz bands</td>
</tr>
<tr>
<td>Technology</td>
<td>• GaAs → SiGe BiCMOS HBT</td>
<td>• Integrated functions, logic, scan, self-test, etc.</td>
</tr>
<tr>
<td></td>
<td>• Bare Die → Packaging</td>
<td>• Broadens market, reduces assembly complexity</td>
</tr>
<tr>
<td>Feature, Function, Performance</td>
<td>• Short → Med, Long Range</td>
<td>• Higher frequency, phase shifting</td>
</tr>
<tr>
<td></td>
<td>• Higher resolution target discrimination</td>
<td>• DBF/SAR</td>
</tr>
<tr>
<td></td>
<td>• 360 Coverage</td>
<td>• Signal discrimination, filtering</td>
</tr>
<tr>
<td></td>
<td>• Lower power consumption</td>
<td>• Reduced cost radar modules</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Improved trans lines, HBT Ft</td>
</tr>
</tbody>
</table>
Radar Regional Demand Forecast

- EU volume leads
  - Early adoption, truck mandate
- Japan truck mandate started 2013
- Adoption in North America driven by cost, followed by legislation

Projected Radar Demand by Region

[Graph showing demand projections by region from 2007 to 2018, with EU leading and Japan mandate starting in 2013.]

Demand (K Units)


Legend: NAFTA, JPN, EU, SK, CHN, IND, BRZ, RUS, ROW
Radar Package Requirements
Critical Requirements for a 77GHz Radar Package

- General package requirements
  - Low cost
  - Excellent RF isolation and controlled impedance
  - BGA package preferred
  - I/O on outer rows of package ball array to enable board routing
- 77GHz performance – low insertion loss, low loss dielectrics
  - Minimize loss from die to user circuit board
  - Minimize attenuation
- Good thermal performance
  - Radar die can dissipate 1-2 watts in automotive ambient temperature of 125C
- Reliability requirements
  - Automotive safety requiring AEQ-100 G1 reliability
  - Solder Joint Reliability >1000 cycles
- Future capabilities
  - Multi-die and passive component integration in radar package
Radar Package Solution – Redistributed Chip Package (RCP)
Freescale’s Redistributed Chip Package

- Package size reduction
- Cost competitive, high productivity, large area batch process
  - Eliminates package substrate
  - Eliminates gold wire bonds / C4 bumps
- High performance package
  - Reduced electrical parasitics
  - Higher frequency response
- Ultra Low-k compatible (<90 nm MLM)
  - Compliant with advance Si technology
- Pb-free, halogen free, ROHS compliant
- Single chip, multiple chip and embedded component capability
- 3-D IC enabling with system integration roadmap
- Certified to JEDEC/FSL Commercial, Industrial, Automotive Level Reliability at the High Volume Manufacturing site

300 mm round panel
9 x 9 mm packages
258 IO, 0.5 mm pitch
716 packages/panel
2 layer build-up
RCP Process

• Wafer reconstitution with KGD
• Space creation to accommodate more I/O’s and sophisticated routing

• Build up process with “Fan-out” routing
• Multiple RDLs (Redistribution Layer) possible
• Physical protection for die
2ML RCP Package Design Construction (die down)

die pad
via1
M1 layer
via2
M2 layer (BGA)
solder bump/solder ball
PCB
(not part of RCP package)
RCP Package Evolution

Radar ➔ Single Die, 1 Metal Layer

Single sided build up - Single Die

Single sided build up - Multi Die, SMT

Double sided build up - RCP Stacking System Integration

2ML

Increasing Metal Layers

4ML

PA, TxRx, RF Modules

Power Control

DSP

2G, 3G Baseband, Power Management

Increasing Integration

3D

Stacking

2.5G Radio-in-Package

3G Radio-in-Package

RCP-PoP

RCP-3D MEMS

Stacked RCP
Radar in RCP

77 GHz radar transmit and receiver die in RCP

- Small (6x6mm) RCP package (1 metal layer)
- Short transmission lines (die pad to solder ball)
- Can expose back of die for heatsink
- Embedded Ground Plane for ground and shielding
- Can embed an antenna structure
Packaged Radar in RCP

ATTRIBUTES:
- Single die
- 1 metal layer
- 6x6mm body size
- 0.5mm pitch
- 0.3mm solder ball diameter
- Leadfree
Packaged Radar in RCP: X-ray Image

- RCP package
- Chip
- Distribution layers
- BGA
- PCB
M77 GHz Package
Freescale RCP (Redistributed Chip Package)

Cross-section

Build-up

Die

Cross-section
Radar Package Performance
RCP Radar Reliability Results

<table>
<thead>
<tr>
<th>Stress</th>
<th>AEC-1 Grade Requirement</th>
<th>Pass / Fail</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>uHAST</td>
<td>96 hrs</td>
<td>Pass (CSAM / Visual Inspection)</td>
<td>Passed extended readout 144hrs</td>
</tr>
<tr>
<td>AATC -50°C to 150°C</td>
<td>1000 cycles</td>
<td>Pass (CSAM / Visual Inspection)</td>
<td>Passed extended readout 2000 cycles</td>
</tr>
<tr>
<td>AATC -65°C to 150°C</td>
<td>500 cycles</td>
<td>Pass (CSAM / Visual Inspection)</td>
<td>Passed extended readout 1000 cycles</td>
</tr>
<tr>
<td>HTS 150°C</td>
<td>1008 hrs</td>
<td>Pass (CSAM / Visual Inspection)</td>
<td></td>
</tr>
</tbody>
</table>
RCP Solder Joint Reliability Results

### Table: RCP Solder Joint Reliability Results

<table>
<thead>
<tr>
<th>Cell</th>
<th>1st Fail</th>
<th># Failed</th>
<th>% Failed</th>
<th># Cycles to % Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA (200 NSMD)</td>
<td>1099</td>
<td>20</td>
<td>63%</td>
<td>2151</td>
</tr>
<tr>
<td>AB (200 SMD)</td>
<td>1371</td>
<td>21</td>
<td>66%</td>
<td>2903</td>
</tr>
<tr>
<td>BC (270 NSMD)</td>
<td>785</td>
<td>19</td>
<td>59%</td>
<td>2151</td>
</tr>
<tr>
<td>BD (270 SMD)</td>
<td>951</td>
<td>22</td>
<td>69%</td>
<td>2151</td>
</tr>
</tbody>
</table>

### Graph: 88 RCP Radar Board-Level Reliability

- **Legend**:
  - AA
  - AB
  - BC
  - BD

- **Inset Table**: 3rd and 95th Percentile
  - 1957 (5.225, 0.885) 32/12
  - 2789 (4.42, 0.942) 32/11
  - 2244 (3.405, 0.968) 32/13
  - 2140 (4.438, 0.967) 32/10

- **Equation**: $r^2 = n/s$

- **Number of Air Temperature Cycles**: -40/125C
Simulation indicates higher strain around the die edges rather than at the package corners.
RCP Test Structures

- Test structures to extract electrical properties at mmwave frequencies (permittivity, loss tangent)
- Test structures to extract transmission losses at mmwave frequencies (insertion loss)
- Validation of EM simulation results
RCP CPW Insertion Loss at 77 GHz

Insertion Loss of RCP CPW Transmission Lines

-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8

Insertion Loss [dB/mm]

frequency [GHz]

- 0.4 dB/mm insertion loss @ 25°C
- 0.5 dB/mm insertion loss @ 75°C
- 0.6 dB/mm insertion loss @ 125°C

• Insertion loss degradation is small across a wide temperature range
Radar Package Tx Test Results

- Package has extremely low-loss of <1dB
- Tested over frequency and temperature for VCO, TX, and RX with low loss
Radar Package Simulation Model

HFSS Model -- RCP_GTX Mounted on Test Board
Package/Die Co-Design

- Clearly defined reference plane in the chip used to model s-parameters
- Matching circuits tuned to match RCP impedance to reduce mismatch loss
- Cascaded s-parameters also be used for board design

HFSS Simulation

Device Zout Provided by Die Designer

Packaged Die Zin Simulated

Packaged Die Zout Simulated

Test Board Zin ~ 50 Ohm Required

Reference Plane at Chip side

Reference Plane at Board side

Impedance Matching Circuit for 50 Ohm

Micro-strip line

Reference Plane

Pad

Chip GND
Package-Board Design Critical

- Measured degraded performance in RX channel
- Potential culprits for signal degradation:
  - On chip
  - On package
  - On the board
- Performed EM simulations to pinpoint areas where performance degradation could occur
Simulation and validation showed variation in channels due to cross-talk on board.

Resolution through introduction of additional vias significantly improve signal integrity.
**MR2001 77GHz Packaged Radar Chipset**

The MR2001 chipset is a scalable radar solution for high end and low end ADAS applications, industrial safety, security, and robotics.

**Differentiating Points**
- Scalable to 4 TX channels and 12 RX channels
- Activate simultaneous Tx channels for electronic beam steering
- Supports fast modulation at 100 MHz / 100 ns
- Integrated baseband filter and VGA saves system bill-of-materials cost
- Local oscillator at 38 GHz to lower the distribution loss and reduce system interference

**Key Characteristics**
- Low power consumption 2.5 W typical for the complete transceiver chipset
- Differential Tx outputs delivering minimum 10dBm with 5-bit digital power control
- Advanced packaging technology with BGA format
- Integrated bi-phase modulator for advanced correlation coding
- Built-in receive chain test mode when using RaceRunner microprocessor
- Best phase noise performance < -85 dBc/Hz at 100 kHz offset, and -95 dBc/Hz at 1 MHz offset
- Temperature detector on each MR2001 chip

**Samples**: Now
**PPAP**: Q3 2014
# 77GHz Packaged Radar Chipset

**Product Differentiation**

<table>
<thead>
<tr>
<th>Scalability</th>
<th>Ease of Use</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design flexibility and integrated features minimize BOM cost</td>
<td>Advanced RCP packaging – highest performing packaged chipset</td>
<td>Exceeding requirements of ADAS and Industrial systems</td>
</tr>
<tr>
<td>• Scalable to 4 TX channel and 12 RX channels</td>
<td>• Advanced RCP packaging – highest performing packaged chipset</td>
<td>• 2.5W typical power consumption for the complete transceiver</td>
</tr>
<tr>
<td>• Simultaneous Tx channels for electronic beam steering</td>
<td>• Integrated temperature and power sensors ensure optimal system performance</td>
<td>• Best phase noise performance to improve target separation</td>
</tr>
<tr>
<td>• Integrated baseband filter and VGA</td>
<td>• Integrated receive signal path integrity testing of all Rx channels</td>
<td>• 38 GHz local oscillator (vs. 77) lowers distribution loss and reduces system interference</td>
</tr>
<tr>
<td>• SPI control of transmit and LO power for optimal signal levels</td>
<td>• Chipset optimized for interface with the Freescale RaceRunner radar microprocessor</td>
<td>• Supports fast modulation at 100 MHz / 100 ns</td>
</tr>
</tbody>
</table>

Scalable, beam-steerable, open loop VCO radar solution enabling short and long range applications in automotive, industrial safety, security and robotics applications
### MR2001 Radar Transceiver Chipset
#### Features and Benefits

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalable with 4 Tx channels and 12 Rx channels</td>
<td>One RF chipset can be used for low-end to high-end systems for SRR, MRR, and LRR applications</td>
</tr>
<tr>
<td>Activate multiple Tx channels simultaneously</td>
<td>Enables beam steering applications</td>
</tr>
<tr>
<td>Supports fast modulation rates to 100 MHz/100 ns</td>
<td>Fast chirp rates to support SRR, MRR, and LRR enabling low duty cycles for reducing power consumption</td>
</tr>
<tr>
<td>Integrated baseband filter and VGA matched to RaceRunner</td>
<td>Simplifies receive path BOM reducing board area / cost</td>
</tr>
<tr>
<td>Delivered in a high frequency BGA plastic package</td>
<td>Simplifies handling and manufacturing of the radar sensor</td>
</tr>
<tr>
<td>Low power consumption 2.5 W typical for the complete transceiver chipset at 100% duty cycle</td>
<td>Easy placement behind plastic bumpers and other thermally challenging locations</td>
</tr>
<tr>
<td>Phase noise performance $&lt;-85$ dBC/Hz at 100 kHz offset, and $-95$ dBC/Hz at 1 MHz offset</td>
<td>Improved detection and tracking of objects at distances in excess of 200m</td>
</tr>
<tr>
<td>Built-in receive chain test mode when using RaceRunner microprocessor</td>
<td>Allows full testing of the receive chain at 77GHz during operation in safety critical applications</td>
</tr>
</tbody>
</table>
Daughter card for the RaceRunner evaluation kit provides a complete radar reference design with antennas and basic software

Available: Q4 2013
Radar Package Summary
Radar Package Summary

• Automotive Radar will see tremendous growth over the next 4 years with a focus on a packaged radar solution

• The requirements for packaged automotive radar solutions are: excellent RF isolation, controlled impedance, low insertion loss, low attenuation, good thermal dissipation and automotive reliability

• The Freescale solution in an redistributed chip package meets the challenging automotive radar requirements
Critical Requirements for a 77GHz Radar Package

• **General package requirements**
  - Low cost
  - Excellent RF isolation and controlled impedance
  - BGA package preferred
  - I/O on outer rows of package ball array to enable board routing

• **77GHz performance – low insertion loss, low loss dielectrics**
  - Minimize loss from die to user circuit board
  - Minimize attenuation

• **Good thermal performance**
  - Radar die dissipate 1-2 watts in automotive ambient temperature of 125°C

• **Reliability requirements**
  - Automotive safety requiring AEQ-100 G1 reliability
  - Solder Joint Reliability >1000 cycles

• **Future capabilities**
  - Multi-die and passive component integration in radar package
For Further Information

- SME Contact information
  - Darrel Frear
  - Darrel.frear@freescale.com
Sample Session Closing

By now, you should be able to:

• Effectively describe, at a high level, the automotive radar application space

• Apply the knowledge gained in this presentation to develop board-level solutions for automotive radar

• Discuss the meaning of key terms used when designing products leveraging packaged radar

• Describe the common components of the packaged radar solution