Mobile Phone Thermal Design Analysis

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March 18, 2013

Acknowledgement

- Information from the following websites is used for this analysis
  - http://www.ifixit.com/Teardown/iPhone+5+Teardown/10525/1
  - http://www.ubmtechinsights.com/apple-iphone-5/
  - http://www.ifixit.com/Teardown/Samsung+Galaxy+S+III+Teardown/9391/2
  - http://www.jsw.co.jp/en/mg_f/mg_mg_f/mg_mg_chare.htm
  - http://guide-images.ifixit.net/igi/RNMLIQRsTCG5KeXS.medium
  - http://www.symbiantweet.com/nokia-lumia-920-and-lumia-820-fcc-teardown-pictures
  - http://www.micron.com/~/media/Documents/Products/Technical%20Note/MCP/TN_10%2008.pdf
  - http://www.ifixit.com/Teardown/iPhone+4S+Teardown/6610/1
  - http://www.furukawa.co.jp/review/fr025/fr25_14.pdf
  - http://www.apple.com/
  - http://downloadcenter.samsung.com/content/UM/201207/20120706131108550/VZW_SCH-i535_English_User_Manual_LG1_F5.pdf
  - http://docs.blackberry.com/en/smartphone_users/deliverables/49805/BlackBerry_Z10_Smartphone-Safety_and_Product_Information-1339609158831-en.pdf
  - http://www.isuppli.com/Teardowns/News/pages/iPhone5-Carries-$199-BOM-Virtual-Teardown-Reveals.aspx

- Reference paper

  - V.D. Santis, “Ear Temperature Increase Produced by Cellular Phones Under Extreme Exposure Conditions”, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 60, NO. 6, pp. 1728~1734, JUNE 2012

Disclaimer

- The analysis provided in this presentation is solely based on public information of device teardowns and vendor publications from the websites listed in the previous slide.
- The analysis is speculative in nature and reflects the views of the author only. The author is solely responsible for the accuracy or mistakes in this analysis.


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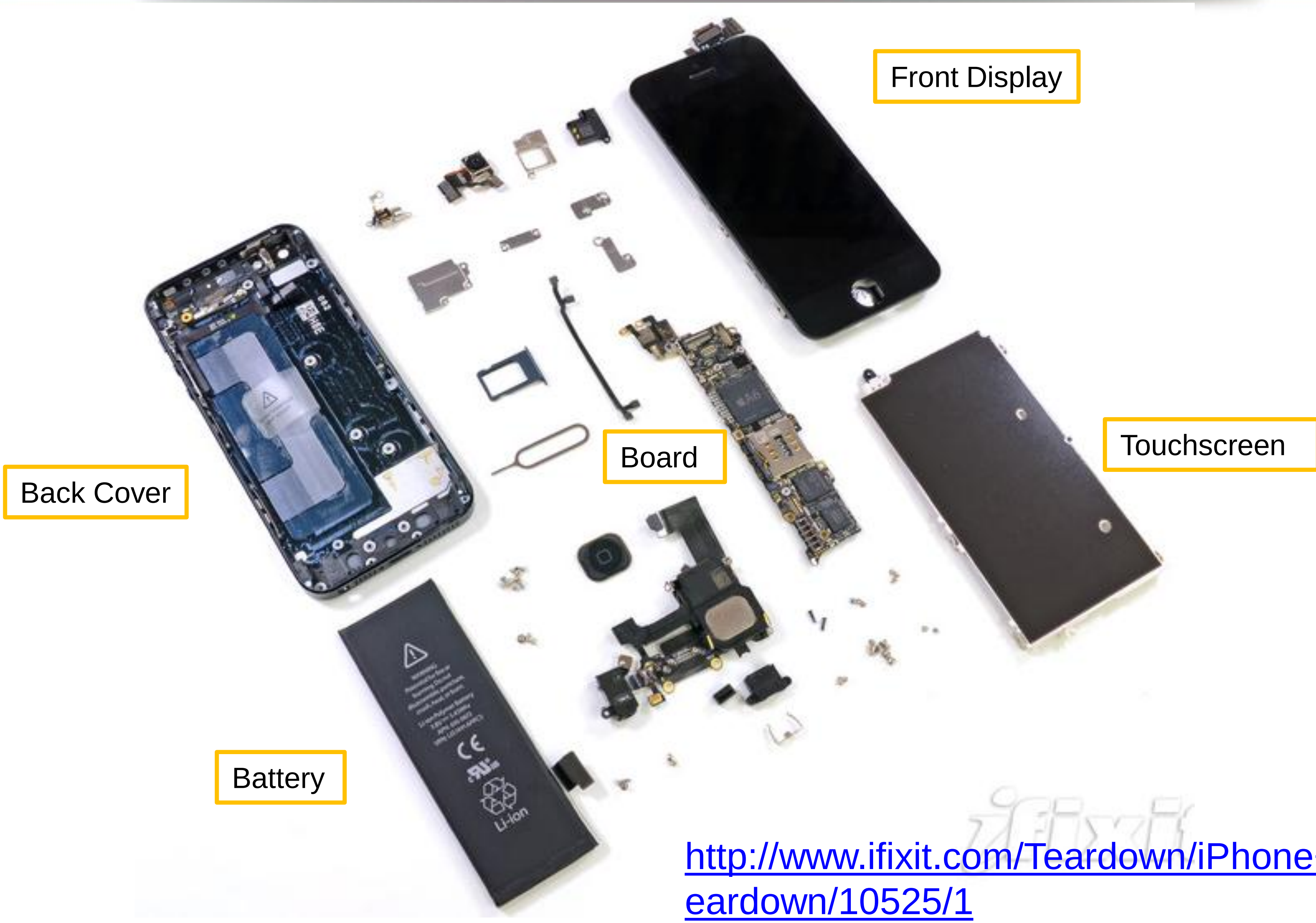
iPhone® 5

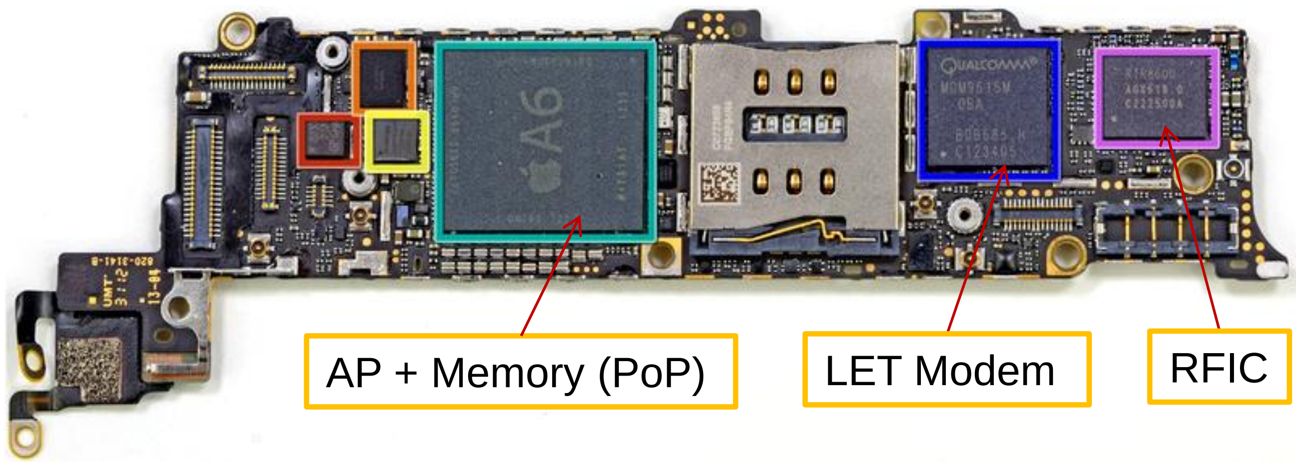
iPhone 5 Teardown



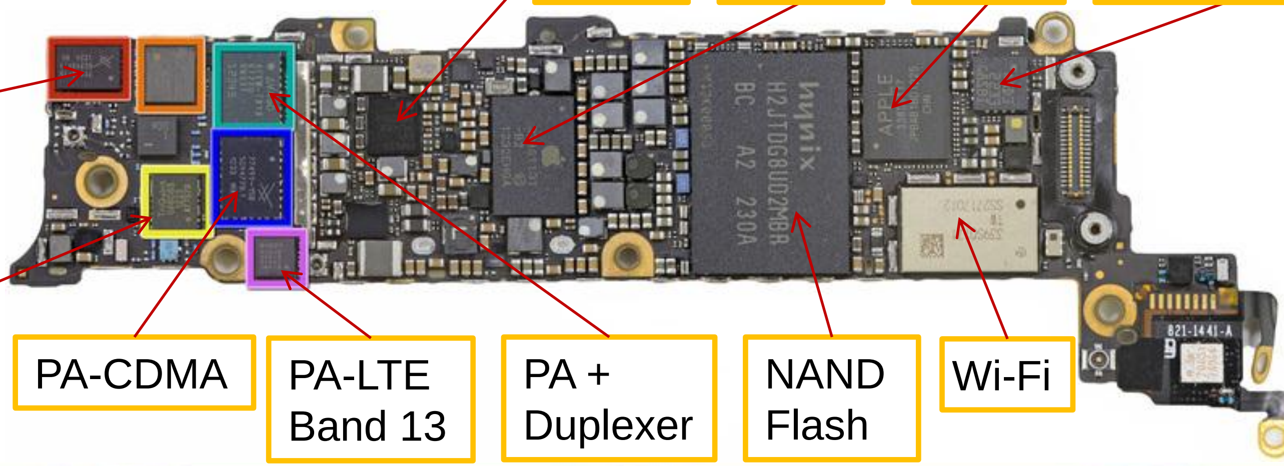
http://www.ifixit.com/Teardown/iPhone+5+Teardown/10525/1

Logic Board – Primary Heat Sources

- **Frontside (facing display)**



- **Backside (facing back cover)**

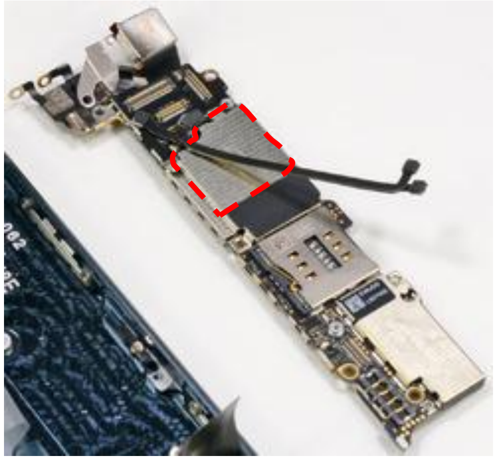


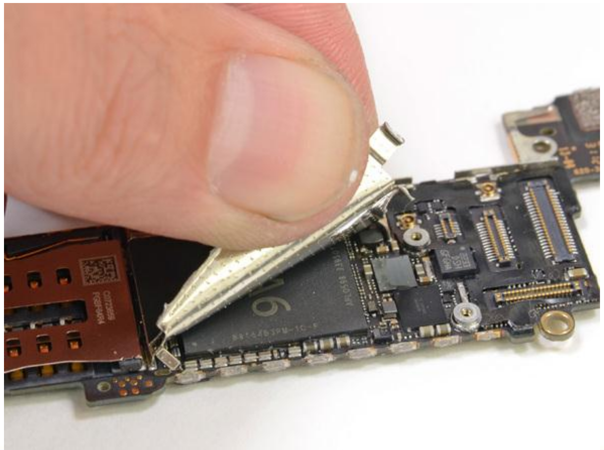
Inside iPhone 5 – Front View

- Logic board is the primary heat source.
- Plastic tab separates battery from logic board.
- Battery is covered with tape on both sides.
  - Graphite heat spreader?

Logic Board Thermal Analysis – Frontside

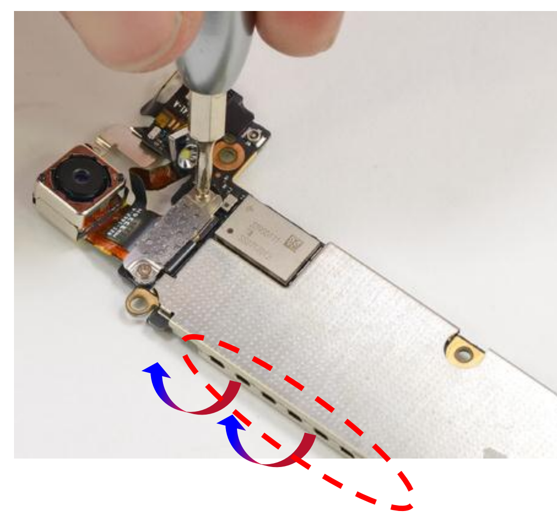
- No thermal interface material (TIM) on PCB frontside.
- Plastic tab separates PCB from display metal plate.
- A6 is wrapped under metallic shield tape.





Logic Board Backside and Aluminum Case

- Metal shield covers all PCB backside ICs except the Wi-Fi IC.
  - Are the small openings on the EMI shield side wall for hot air to escape?
  - Is there TIM under the EMI shield as used in previous iPhone designs?
- Aluminum case under the PCB appears to be thicker.
  - Thicker wall for better heat spreading
- TIM lining appears to be on the inner surface of the Al case.



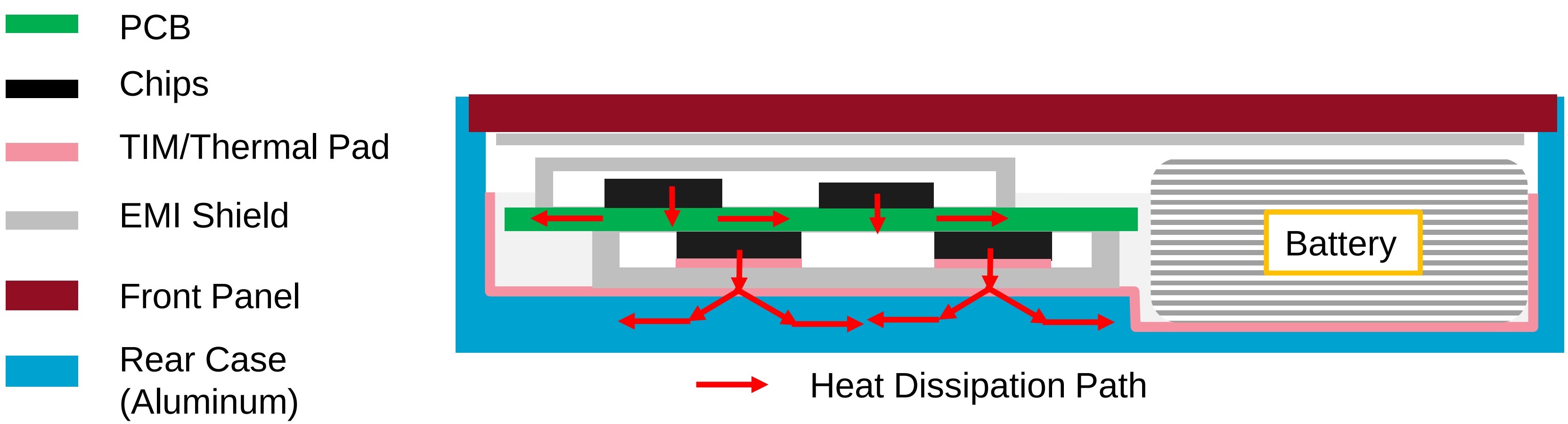
http://www.ifixit.com/

http://www.ubmtechinsights.com/

Thermal Solution Summary – iPhone 5

- Conductive path for heat dissipation to aluminum back cover

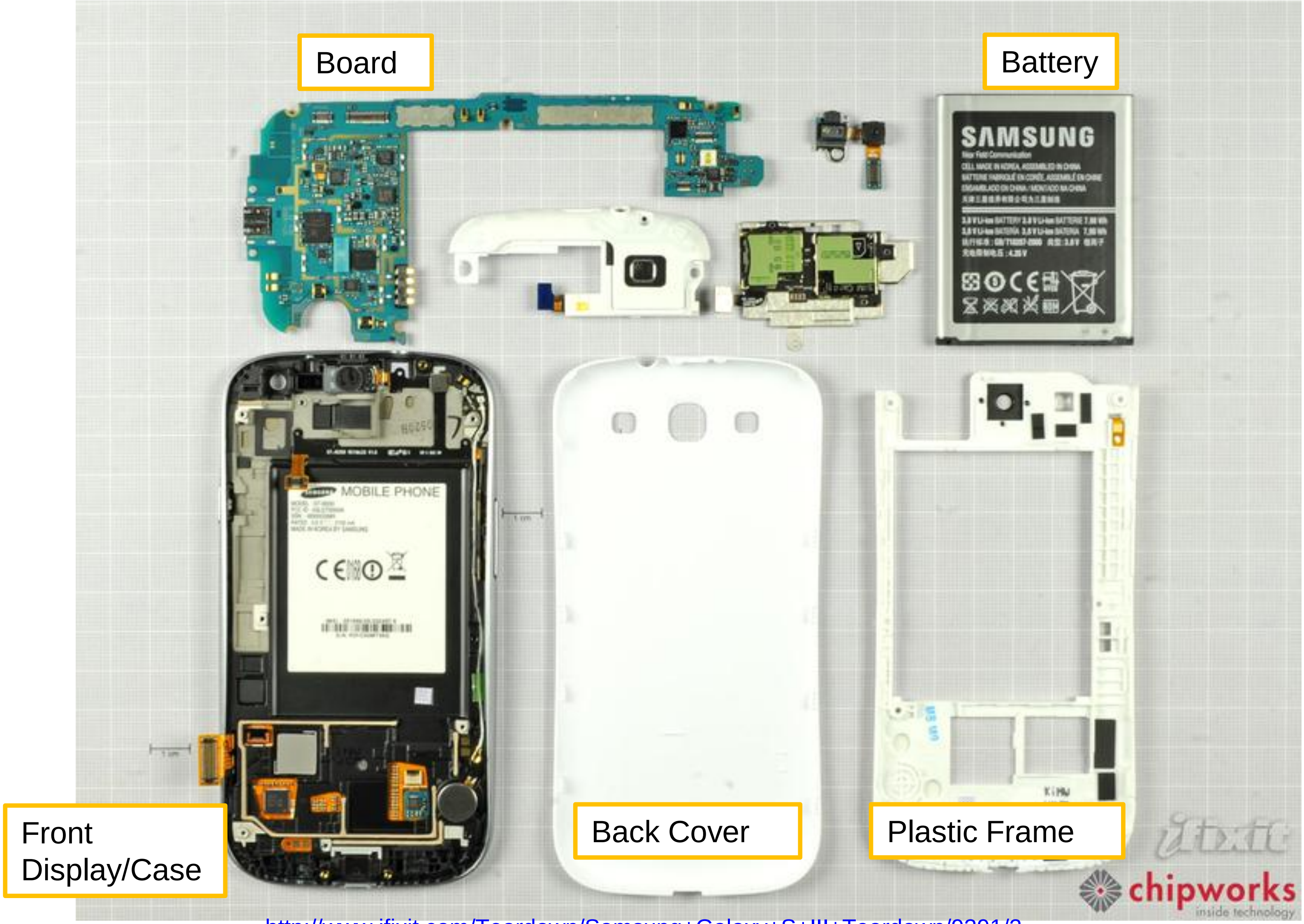
Chips → TIM Pad → EMI Shield → TIM Liner → Back Cover



- Aluminum rear case replaced glass back cover.
  - Aluminum wall under logic board appears to be thicker to help heat spreading.
- Rare case inner surface is probably lined with a large piece of TIM pad.
  - Helps dissipate heat from the EMI shield to the aluminum case.

Samsung® Galaxy S III

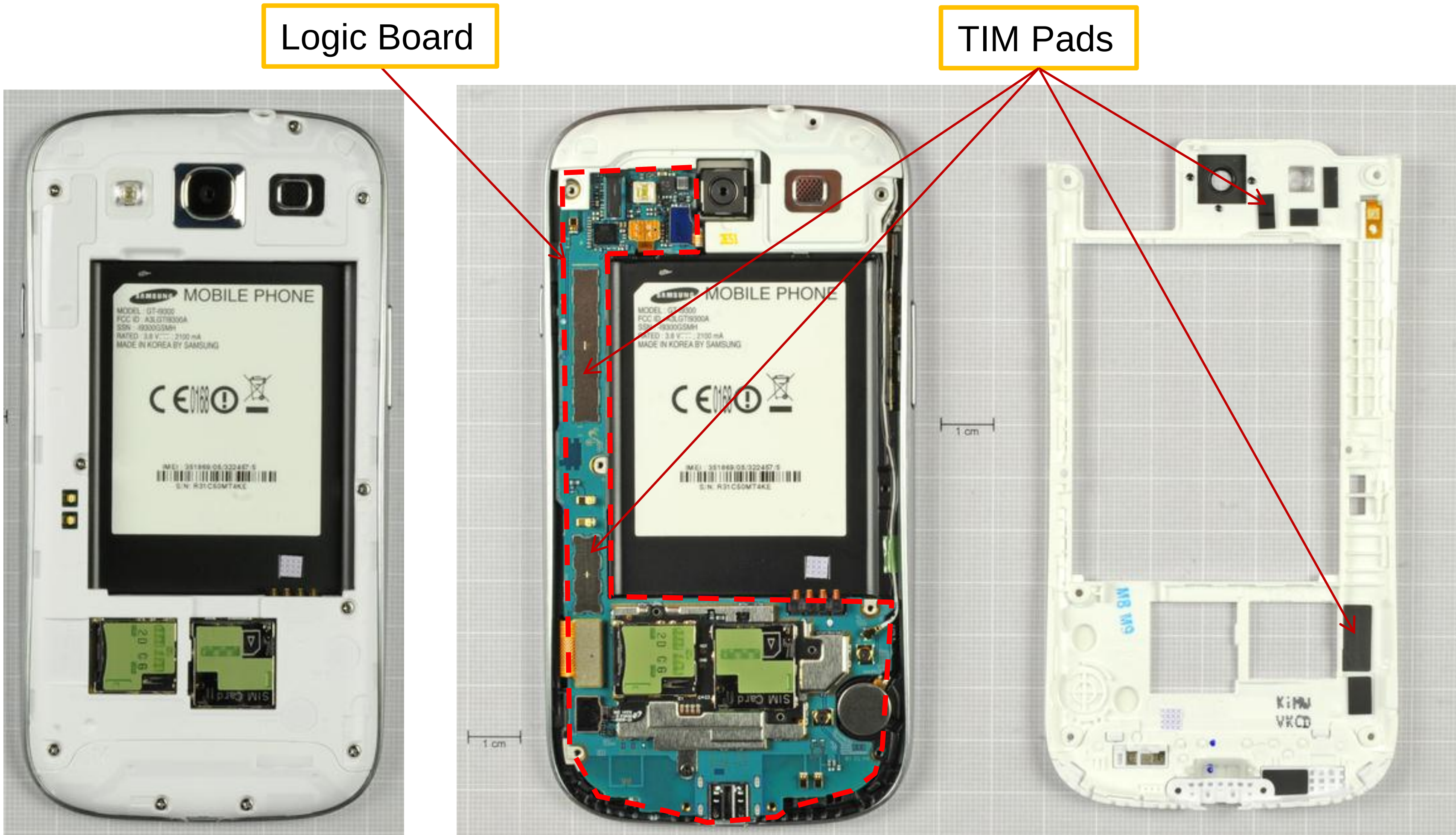
Teardown View



http://www.ifixit.com/Teardown/Samsung+Galaxy+S+III+Teardown/9391/2

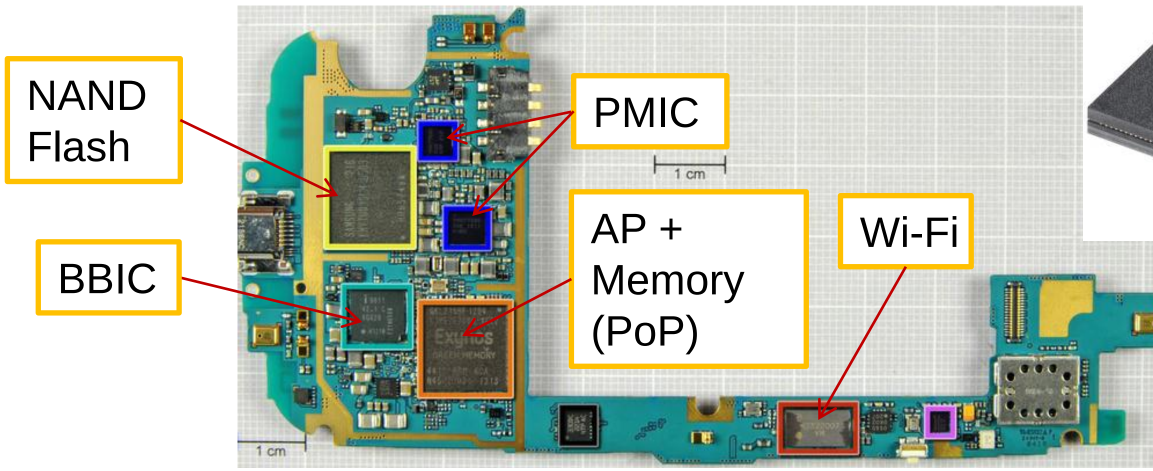
Logic Board Location – Back Cover Removed

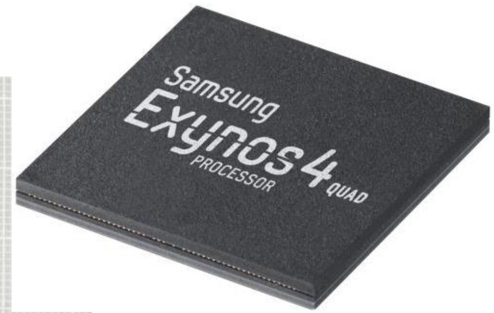
- TIM pads on both PCB and plastic frame



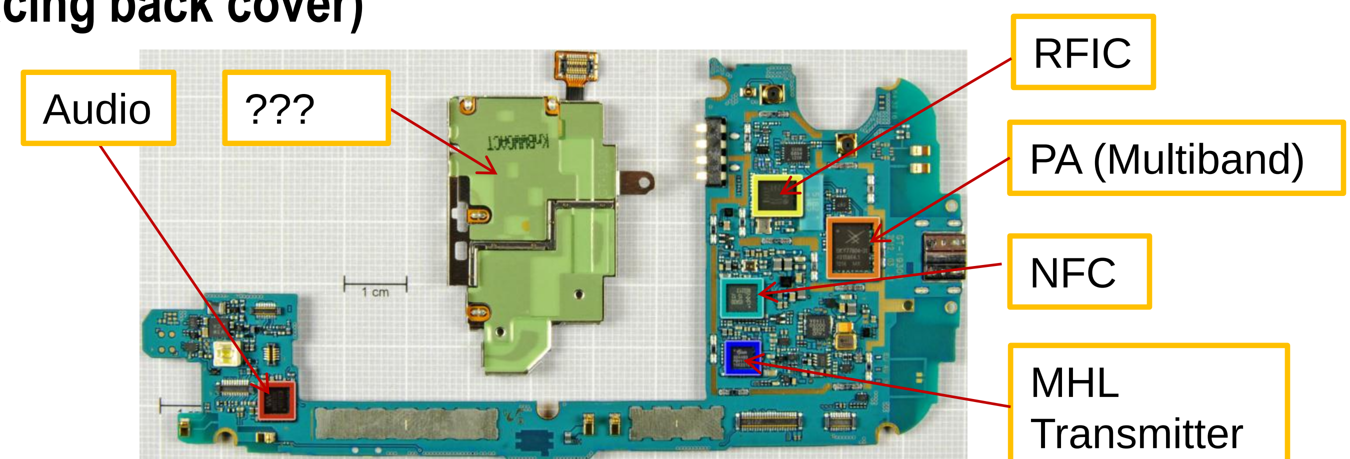
Logic Board – Primary Heat Sources

- **Frontside (facing display)**





- **Backside (facing back cover)**



Metal Frame Support

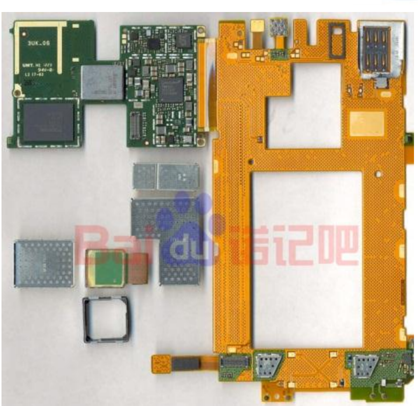
- Metal frame might be magnesium.
  - Better for thermal
- Magnesium frame may also have been used in Galaxy S 4G.

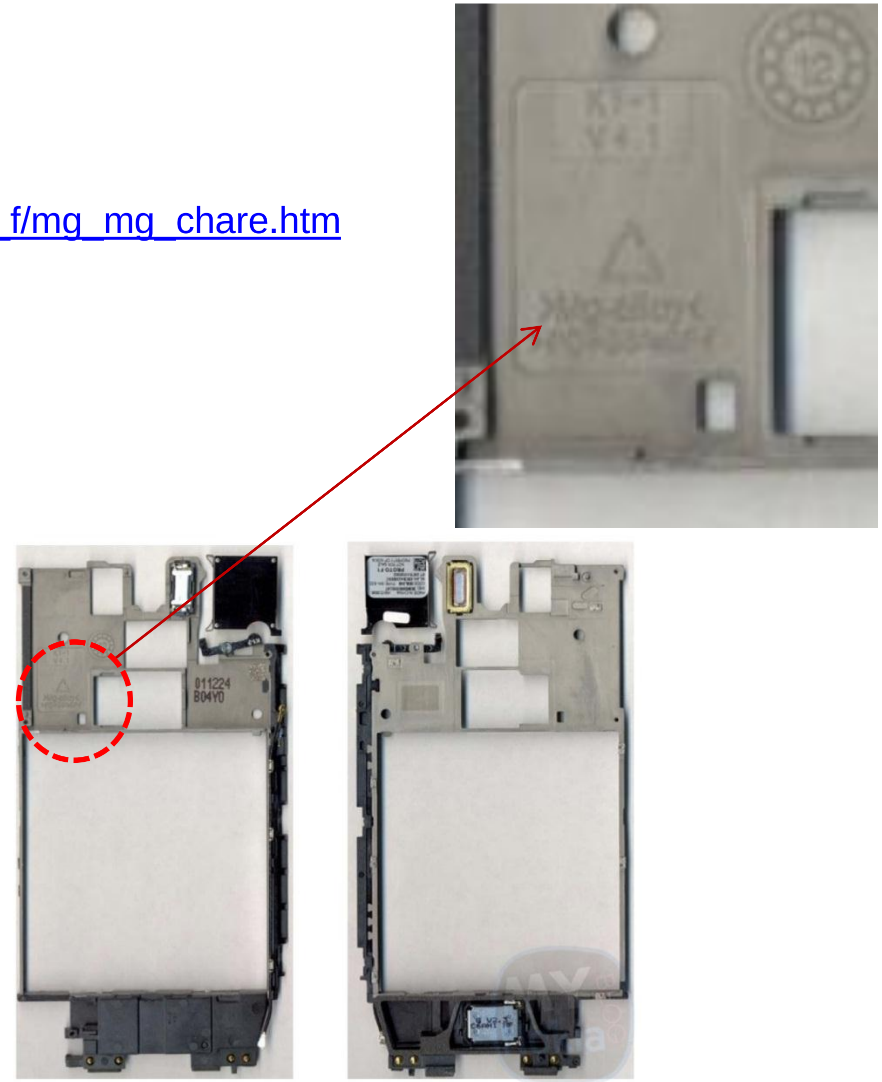
Magnesium Frame

http://guide-images.ifixit.net/igi/RNMLIQRsTCG5KeXS.medium

Nokia® Lumia 920 Magnesium Frame

- Magnesium frame
  - High strength-to-weight ratio
  - Good thermal conductivity (62~72 W/m·K)
    - Source: http://www.jsw.co.jp/en/mg_f/mg_mg_f/mg_mg_chare.htm
  - Windows® Phone Lumia 920 Mg-alloy frame





http://www.symbiantweet.com/nokia-lumia-920-and-lumia-820-fcc-teardown-pictures

Thermal Solution Summary – Galaxy S3

- Conductive path for heat dissipation to back cover

  Chips → TIM Pad → EMI Shield → Magnesium Frame

PCB
Chips
Thermal Pad
EMI Shield
Mg Frame
Front Panel
Back Cover
Heat Dissipation Path

- EMI shield is used to promote heat spreading of IC components.
- Thermal interface materials are used to provide thermal coupling between IC components and EMI shield.

Thermal Enhancements and Constraints

More on Metal Frames

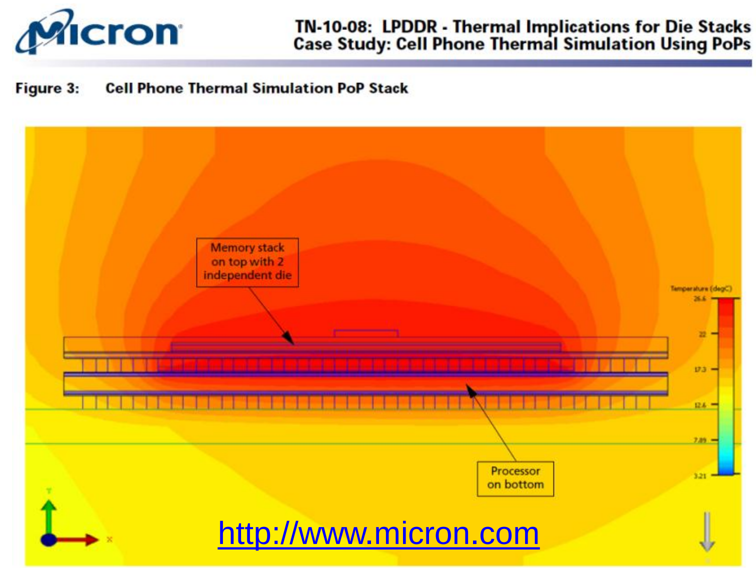
- Phone casing materials: plastics, glass, and aluminum
- Structural frame materials: plastics, stainless steel, and magnesium
  - Structural support, EMI shielding, and thermal

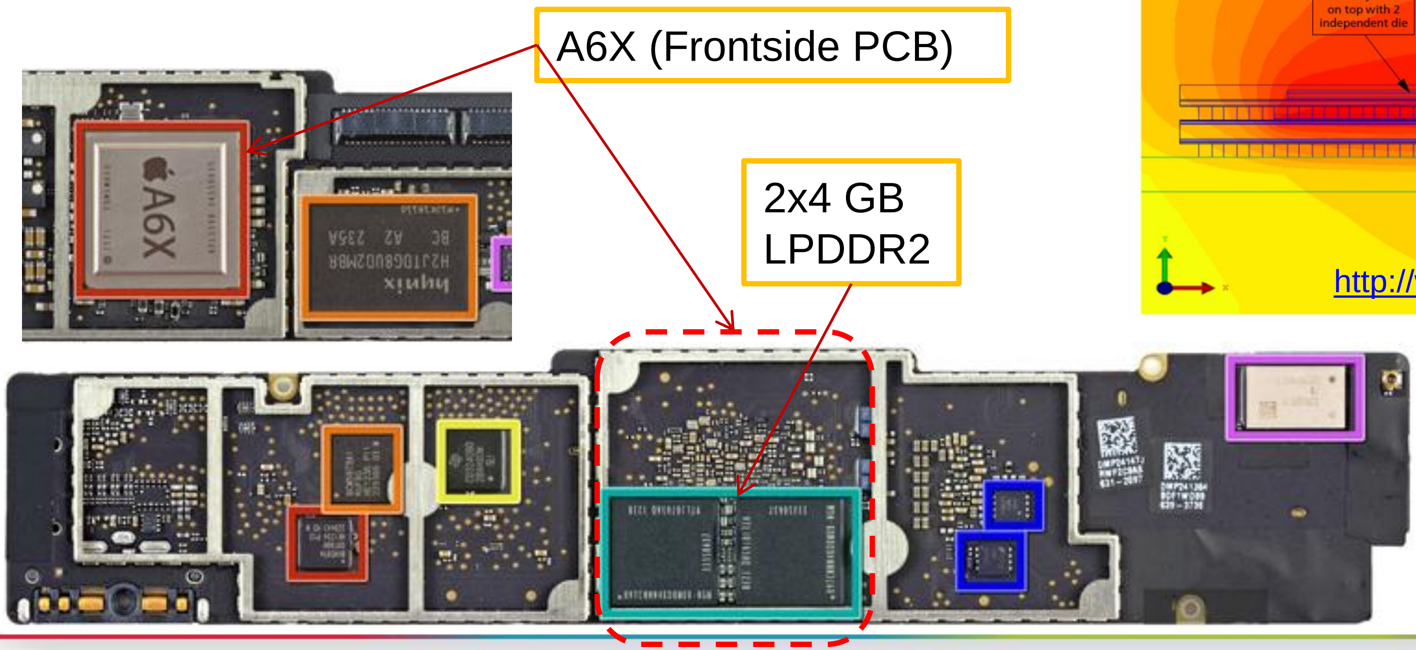
http://www.jsw.co.jp/en/mg_f/mg_mg_f/mg_mg_chare.htm

NAME		Density (g/cm^3)	Melting Temperature (°C)	Thermal Conductivity (W/Mk)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Specific Strength	Young's Modulus (GPa)
Magnesium alloy (Thixomolding)	AZ91	1.82	596	72	280	160	8	154	45
	AM60	1.79	615	62	270	140	15	151	45
Aluminum alloy (die casting)	380	2.70	595	100	315	160	3	117	71
Steel	Carbon Steel	7.86	1520	42	517	400	22	66	200
Plastics	ABS	1.03	90 (Tg)	0.2	35	*	40	34	2.1
	PC	1.23	160 (Tg)	0.2	104	*	3	85	6.7

PoP Thermal Constraints

- Top memory temperature is very close to bottom ASIC.
- T_{Jmax} mismatch between memory and ASIC: 95–105℃ vs. 125℃
  - Thermal design must keep PoP memory T_J at 95–105℃.
  - ASIC T_J cannot exceed 95–105°C.
- Solution: memory on backside of PCB?
  - iPad® 4



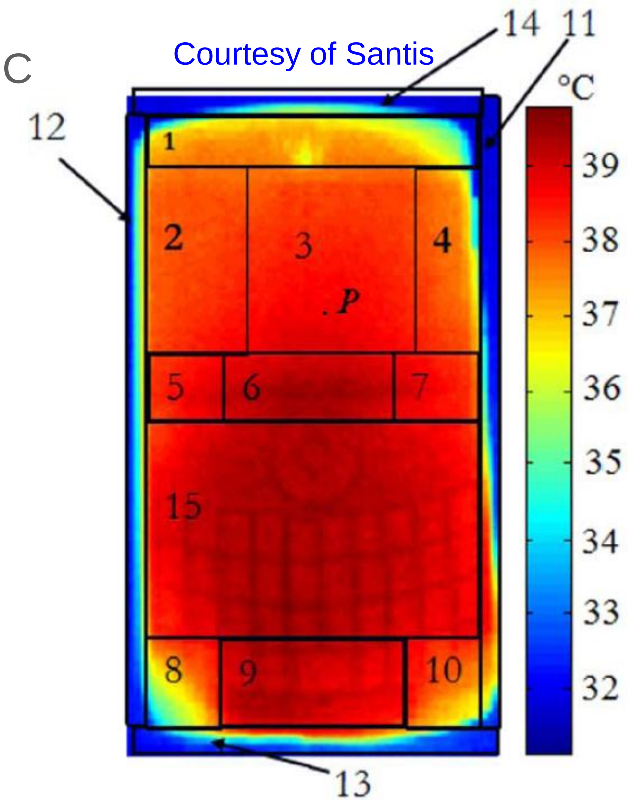


http://www.ifixit.com/Teardown/iPad+4+Teardown/11462/1

Temperature Mismatch Constraints

- "Skin Temperature" limit (T_{skin}): 45°C–55°C
  - Metal case vs. plastic/glass case: typically ~5°C lower for metal
- Mobile phone vendor temperature specifications
  - iPhone 5
    - Nonoperating temperature: below 0°C and above 45°C
  - Galaxy S3
    - Avoid temperature below 0°C and above 45°C.
  - BlackBerry® Z10
    - Device operating temperature: 0°C to 35°C
- Li-ion battery temperature limit (T_{batt}): ~50°C
  - Lifespan
  - Thermal runaway

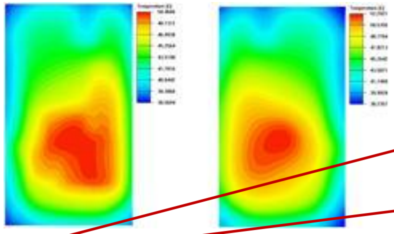
Courtesy of Santis



Refs:
- http://www.apple.com
- http://downloadcenter.samsung.com/content/UM/201207/20120706131108550/VZW_SCH-i535_English_User_Manual_LG1_F5.pdf
- http://docs.blackberry.com/en/smartphone_users/deliverables/49805/BlackBerry_Z10_Smartphone-Safety_and_Product_Information-1339609158831-en.pdf
- V.D. Santis, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 60, NO. 6, JUNE 2012

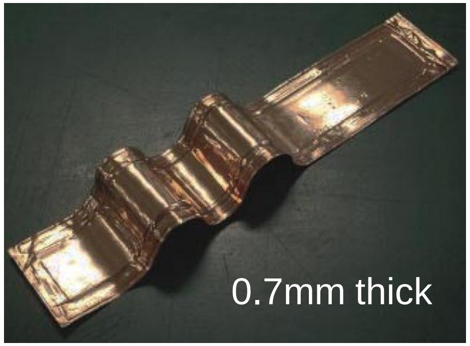
Toolbox for Cell Phone Thermal Designs

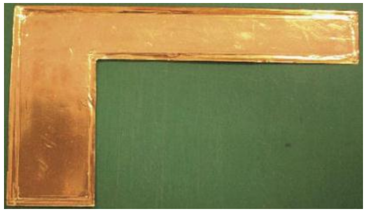
- Modeling and design
  - CFD tools are recommended.
  - Transient mode design
    - Short power bursts of ASICs



http://www.ifixit.com/Teardown/iPhone+4S+Teardown/6610/1

- Thermal management materials
  - Thermal interface materials
  - Graphite heat spreaders
  - Aluminum rear case/metal frame for heat spreading
- Futuristic solutions?
  - Ultrathin heat pipe?
  - Active cooling?
    - Very low profile air movers?
    - TEC devices?



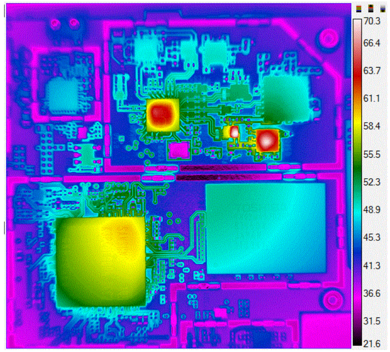


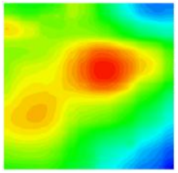
http://www.furukawa.co.jp/review/fr025/fr25_14.pdf

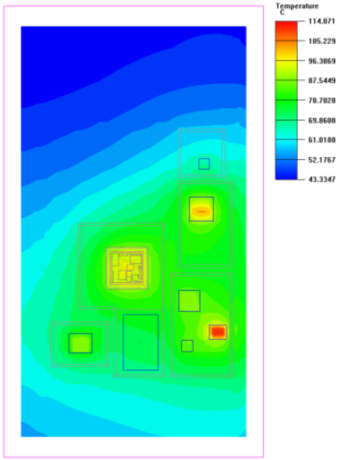
- Conductive heat spreading is the key.
  - Thermal path design innovations
  - Thermal mass for peak activity management
  - New materials and passive thermal devices

Broadcom's Approach

- Thermal design and optimization
  - CFD-assisted chip and platform thermal designs
  - Performance boost transient-mode modeling
  - IR thermal imaging verification
- Maximize performance
  - Evaluate chip design with what-if use-cases
    - On-chip hotspot management
    - Functional blocks floor planning
    - Package thermal via/bump/ball placement
  - Optimize logic-board component placement
    - Meet T_J, T_{skin}, and T_{batt} design targets
- Minimize thermal BOM/cost







Challenges to Thermal Solution Suppliers

- Higher performance
  - High k (thermal conductivity)
    - Higher k heat spreaders
      - Ultra-thin heat pipes
      - Graphene nano-based materials
  - Thinner and routable spreaders
  - Low contact resistances
    - Nano-technology based TIM
  - Better chassis/case material
    - Lighter, harder, high k
- Lower cost
  - Mass market acceptance

Preliminary iPhone 5 Bill of Materials and Manufacturing Cost Estimate Based on Virtual Teardown (Costs in U.S. Dollars)

Components / Hardware Elements	iPhone 5 Hardware Comments	iPhone 5 Model 16GByte	32GByte	64GByte
Pricing without Contract		$649	$749	$849
Total BOM Cost		$199	$209	$230
Manufacturing Cost		$8.00	$8.00	$8.00
BOM + Manufacturing		$207	$217	$238
Major Cost Drivers				
Memory				
NAND Flash		$10.40	$20.80	$41.60
DRAM	1GByte LPDDR2	$10.45	$10.45	$10.45
Display & Touchscreen		$44.00	$44.00	$44.00
Processor	A6 Processor	$17.50	$17.50	$17.50
Camera(s)	8 Megapixel + 1. 2 Megapixel	$18.00	$18.00	$18.00
Wireless Section - BB/RF/PA	Qualcomm MDM9615+RTR8600+Front End*	$34.00	$34.00	$34.00
User Interface & Sensors		$6.50	$6.50	$6.50
BT / WLAN	BTv4.0 + Dual-Band Wireless-N	$5.00	$5.00	$5.00
Power Management		$8.50	$8.50	$8.50
Battery	Assumed 1800mAh	$4.50	$4.50	$4.50
Mechanical / Electro-Mechanical		$33.00	$33.00	$33.00
Box Contents		$7.00	$7.00	$7.00

* - Assumed

Source: IHS iSuppli Research, September 2012

http://www.isuppli.com/Teardowns/News/pages/iPhone5-Carries-$199-BOM-Virtual-Teardown-Reveals.aspx

Thank You.

Contact: szhao@broadcom.com