PCB Design Strategies in Handheld Devices

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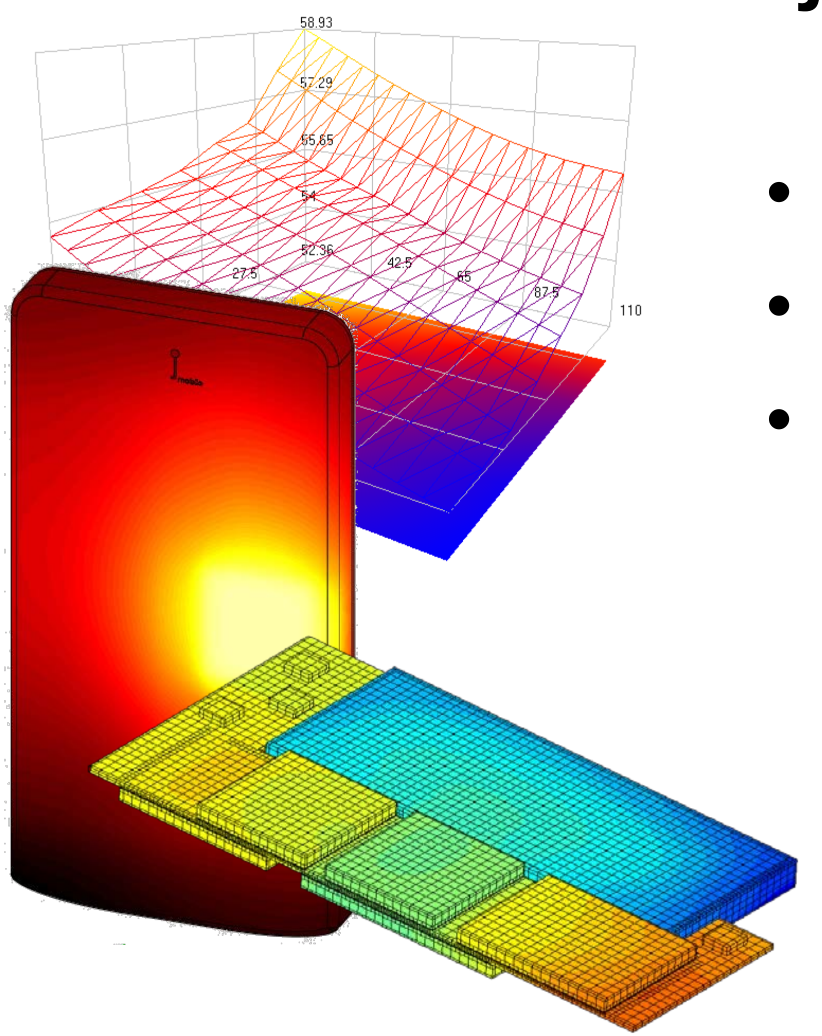
THERMAL LIVE 2015

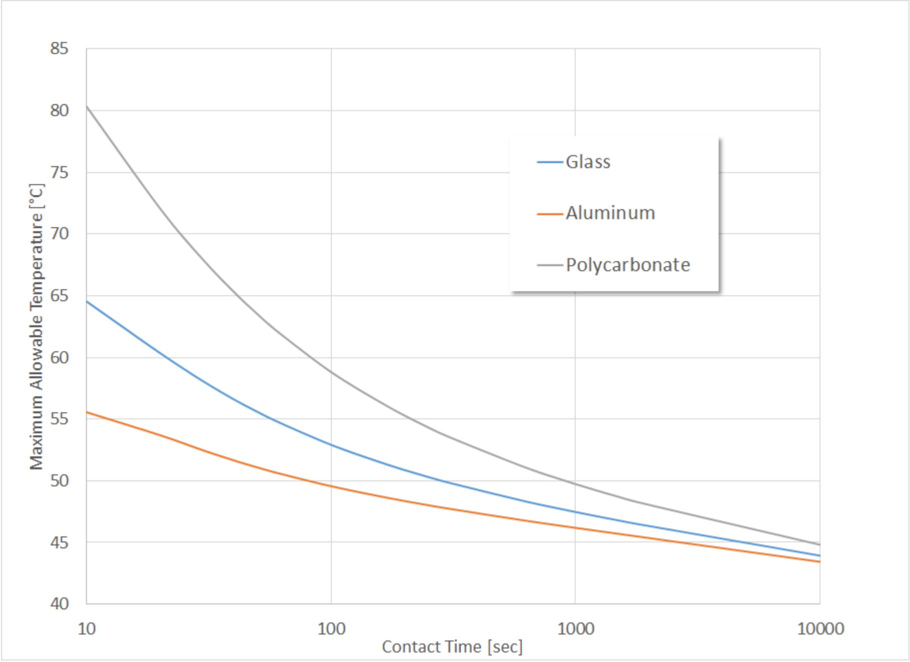
Objectives

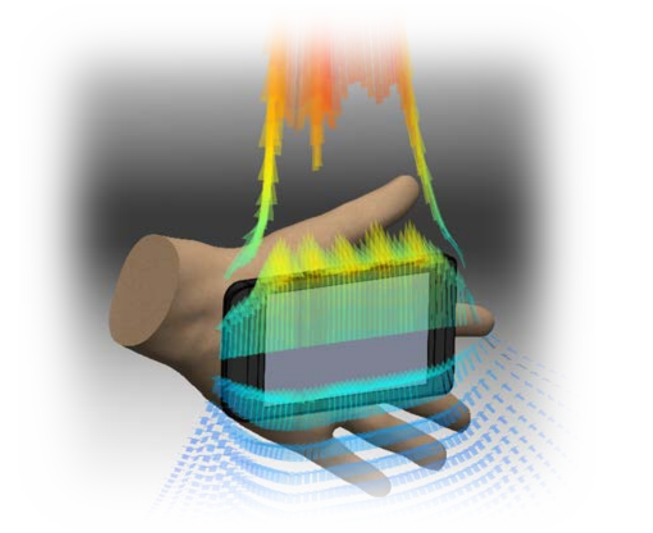


- Criteria
- Options
- Control

Thermal Design Criteria

- Constraints:
  - Chip temperature
  - Outer surface temperature
- Surface Temperature
  - Injury: depends on material and duration
  - Comfort: includes perception



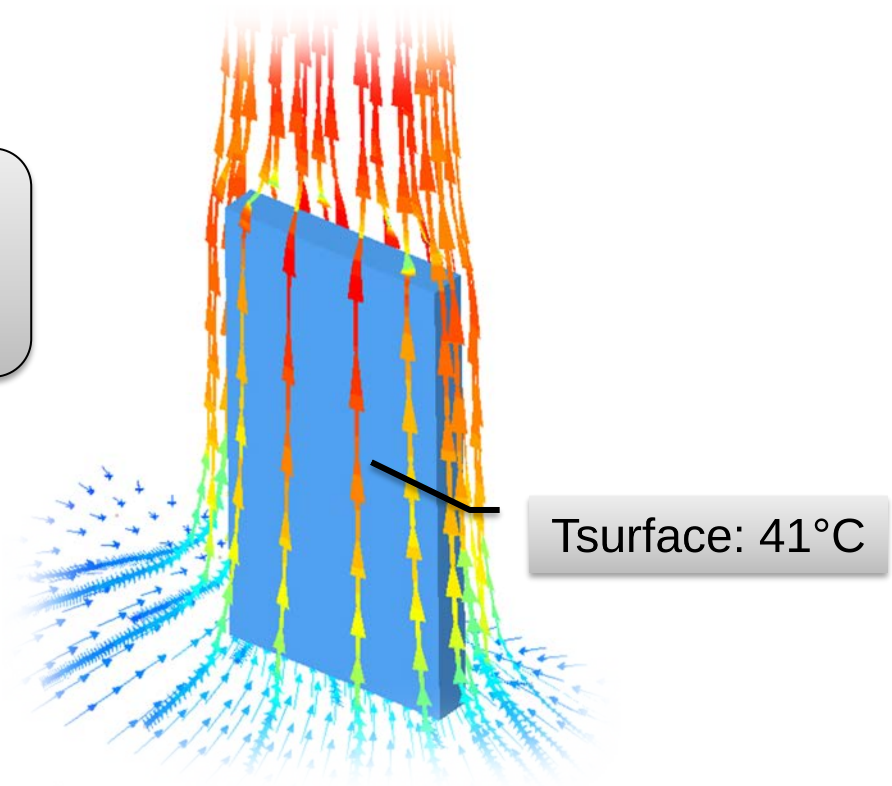


Based on comfort a surface temperature requirement of 41°C is a reasonable value [Berhe]

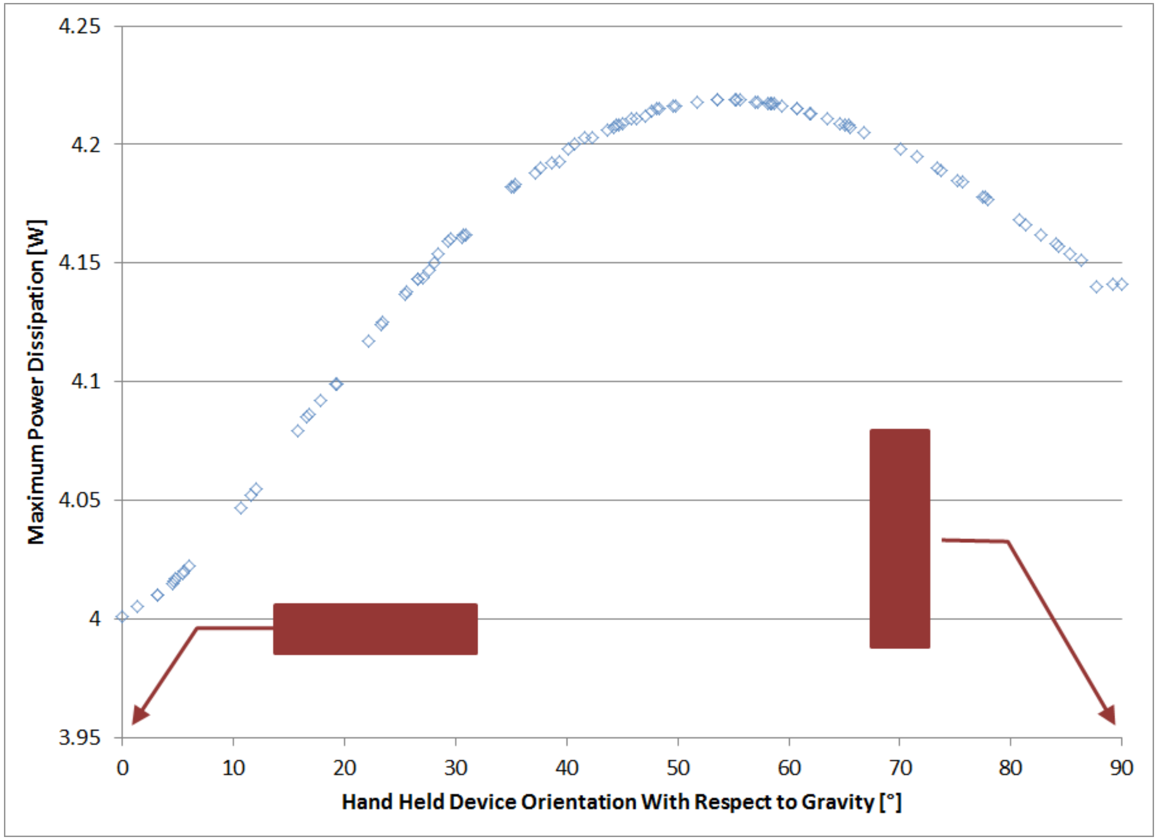
Source: Sanjay K. Roy, An Equation for Estimating the Maximum Allowable Surface Temperatures of Electronic Equipment, 27th IEEE SEMI-THERM Symposium
Source: Berhe, M.K., Ergonomic Temperature Limits for Handheld Electronic Devices, Proceedings of ASME InterPACK'07, Paper No. IPACK2007-33873

Maximum Power Dissipation

Given the optimal convective surface (isothermal) the maximum steady state power dissipation can be determined



Thermal Design Constraints: Smartphone



Typical Smartphone (60x115x10 mm):

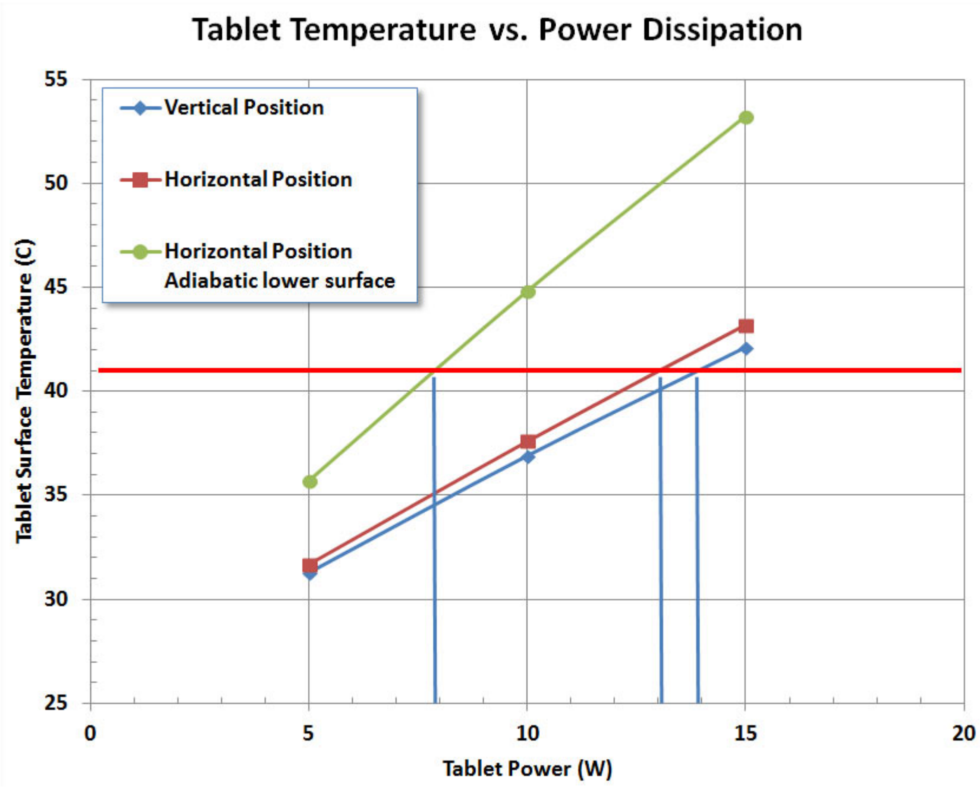
$T_{surface}$: 41°C

T_{amb}: 20°C

emissivity:1

- -Radiation heat transfer ~55%
- -Less than 1% variation in max power with respect to orientation

Thermal Design Constraints: Tablet



Tablet (180x240 mm):

$T_{surface}$: 41°C

T_{amb}: 25°C

emissivity:0.8

-Radiation heat transfer >50%

-Limiting case: 8W

Source: Guy Wagner and William Maltz, A Tablet for Everything, Engineering Edge, Mentor Graphics

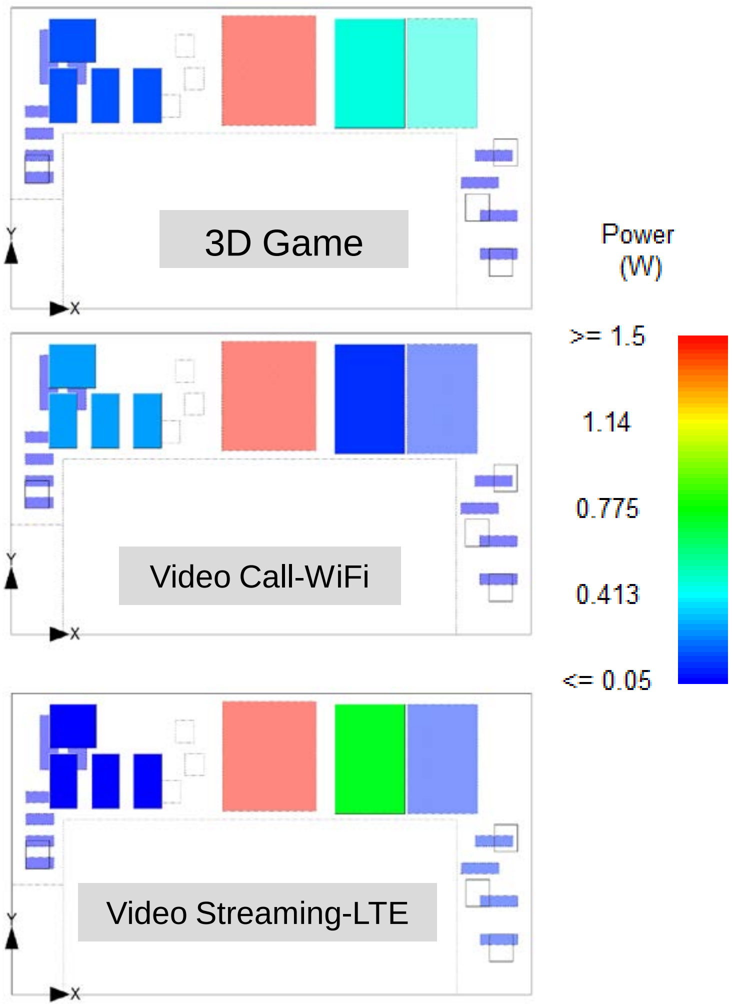
Thermal Design?

- Clever External Fins?

Thermal Design Options

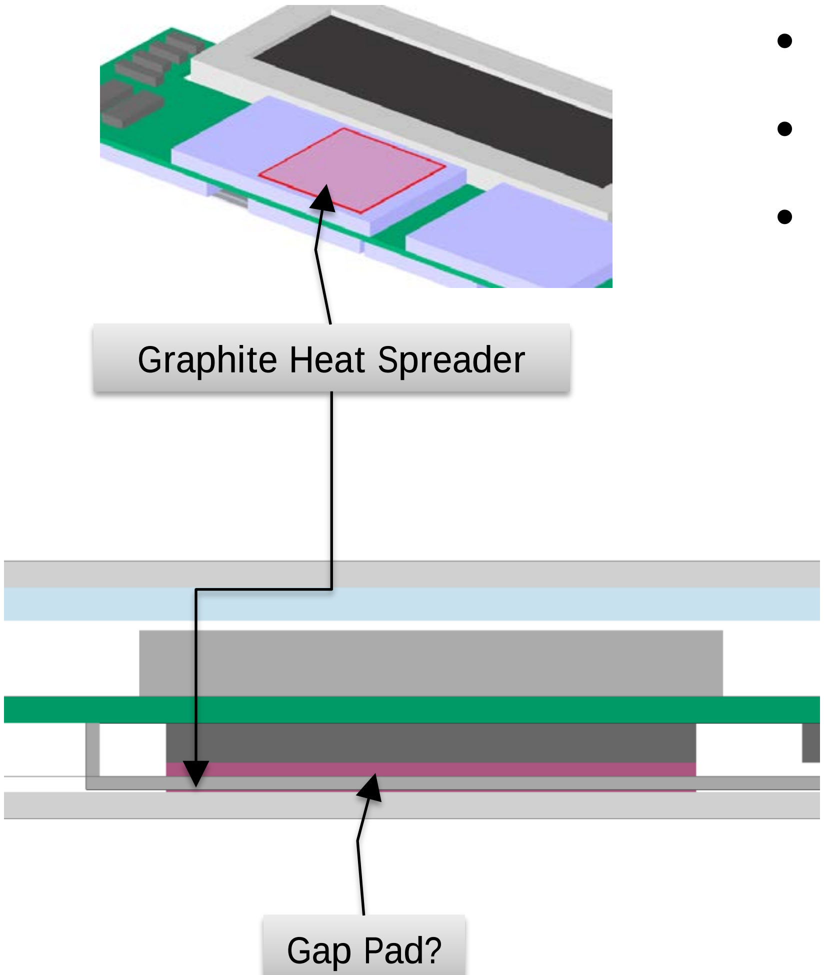
- In a sealed handheld consumer device the thermal design choices are limited
- The options include:
  - Understanding the worst use case scenarios with respect to critical temperatures
  - Manage temperatures through strategic conduction paths and isolation
  - Spread the heat out to minimize temperatures and maximize heat transfer efficiency
  - Phase Change Material?

Steady State Thermal Performance

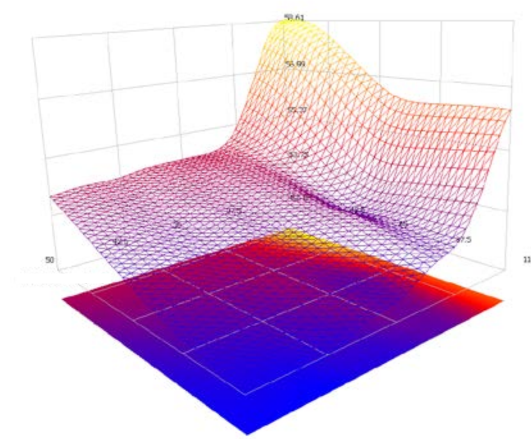


	Use Case					
	3D Game	Video Call-WiFi	Video Call-Cellular	Video Stream-WiFi	Video Stream Cellular	Video Record
U21	49.65	51.65	48.65	50.65	47.65	52.65
U22	49.09	51.09	48.09	50.09	47.09	52.09
U23	47.99	49.99	46.99	48.99	45.99	50.99
U24	48.81	50.81	47.81	49.81	46.81	51.81
U28 [Flash]	49.73	51.73	48.73	50.73	47.73	52.73
U1 [Processor]	56.36	58.36	55.36	57.36	54.36	59.36
U33	50.34	52.34	49.34	51.34	48.34	53.34
U34	50.55	52.55	49.55	51.55	48.55	53.55
U35	50.42	52.42	49.42	51.42	48.42	53.42
U36	49.96	51.96	48.96	50.96	47.96	52.96
U37	48.67	50.67	47.67	49.67	46.67	51.67
U38	48.99	50.99	47.99	49.99	46.99	51.99
U39	46.32	48.32	45.32	47.32	44.32	49.32
U40	46.56	48.56	45.56	47.56	44.56	49.56
U41	46.41	48.41	45.41	47.41	44.41	49.41
U42	45.92	47.92	44.92	46.92	43.92	48.92
U29 [Flash]	48.83	50.83	47.83	49.83	46.83	51.83
Outer Case	45.08	47.08	44.08	46.08	43.08	48.08

Thermal Design: Strategic Conduction



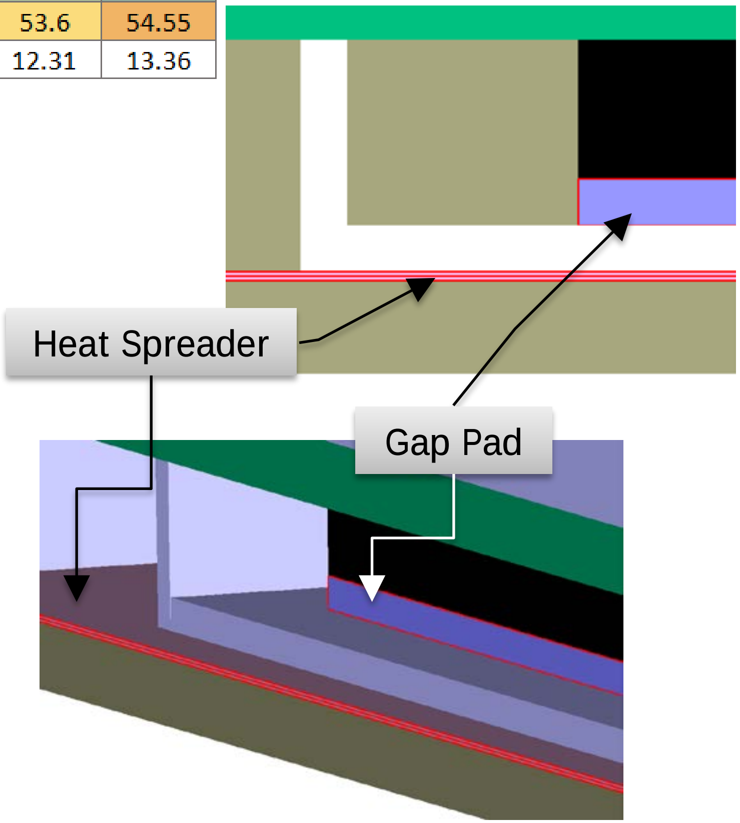
- Should a thermal gap pad be used?
- How much does the heat spreader help?
- What is the optimal size for the Graphite heat spreader?



Design Study: Conduction and Spreading

Scenario	0	1	2	3	4	5	6	7
Gap Pad	Yes	Yes	Yes	Yes	No	No	No	No
Heat Spreader-Inner	Yes	Yes	No	No	No	Yes	Yes	No
Heat Spreader-Outer	Yes	No	No	Yes	No	Yes	No	Yes
Case [°C]	41.39	42.09	49.27	41.85	47.33	40.79	41.29	41.19
Processor [°C]	46.17	47.17	54.13	48.41	58.82	52.87	53.6	54.55
DT [°C]	4.78	5.08	4.86	6.56	11.49	12.08	12.31	13.36

- Highest case temperatures without heat spreader [2 and 4]
- Lowest case temperature with no gap and both spreaders [5]
- Outer spreader only [7] slightly better than inner spreader only [6]



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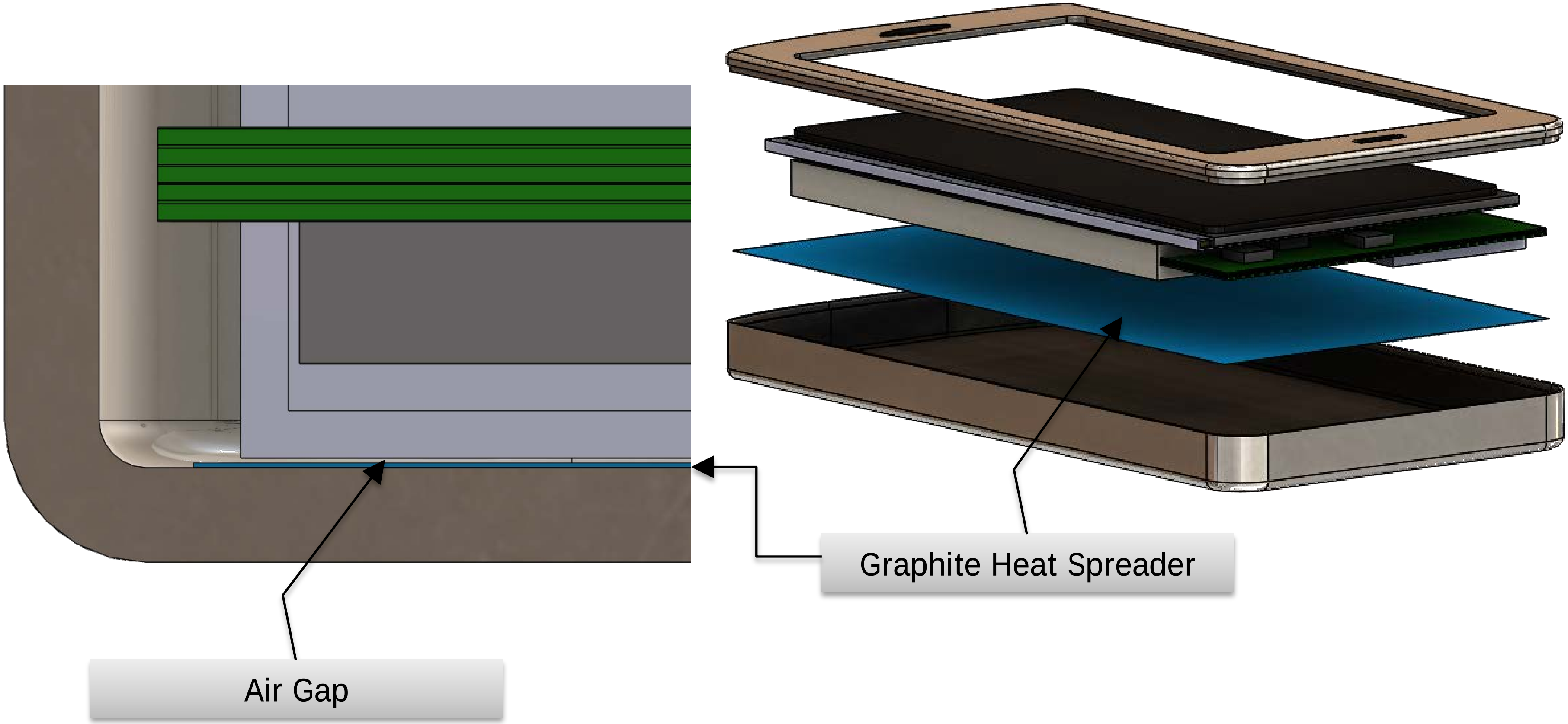
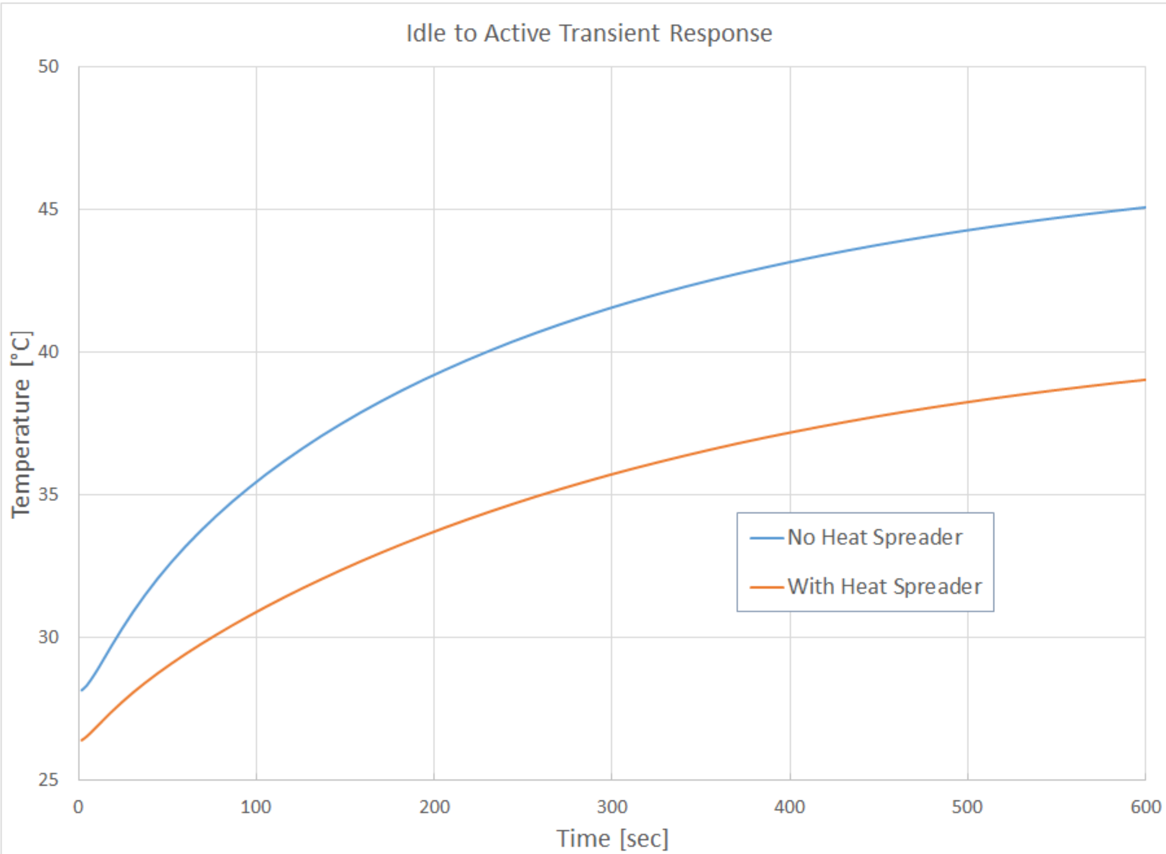
Insulate and Spread the Heat Out



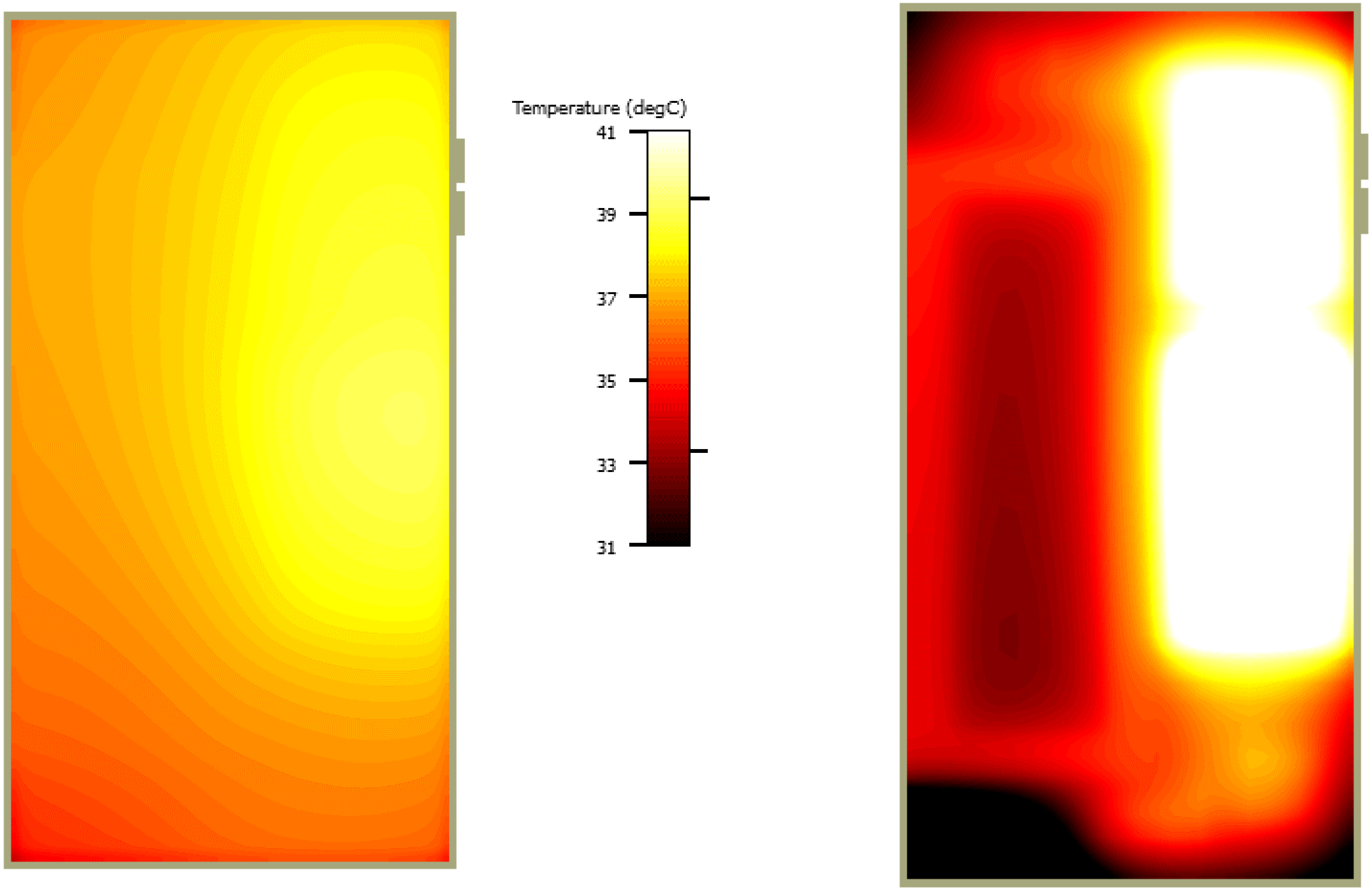
Design Study: Transient Response with Heat Spreader



	Q [W]	
Component	**Active**	**Idle**
Battery	*0.4*	*0.10526*
Backlit LED Array	*1*	*0.26316*
U21	*0.1*	*0.02632*
U22	*0.1*	*0.02632*
U23	*0.1*	*0.02632*
U24	*0.1*	*0.02632*
U28 [Flash]	*0.25*	*0.06579*
U1 [Processor]	*1*	*0.26316*
U33	*0.05*	*0.01316*
U34	*0.05*	*0.01316*
U35	*0.05*	*0.01316*
U36	*0.05*	*0.01316*
U37	*0.05*	*0.01316*
U38	*0.05*	*0.01316*
U39	*0.05*	*0.01316*
U40	*0.05*	*0.01316*
U41	*0.05*	*0.01316*
U42	*0.05*	*0.01316*
U29 [Flash]	*0.25*	*0.06579*
Q Total [W]:	**3.8**	**1**

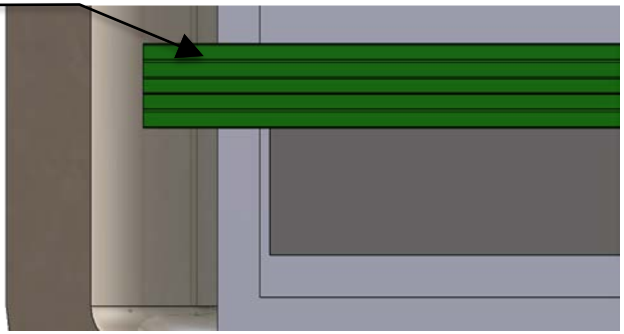
Outer Surface Temperature

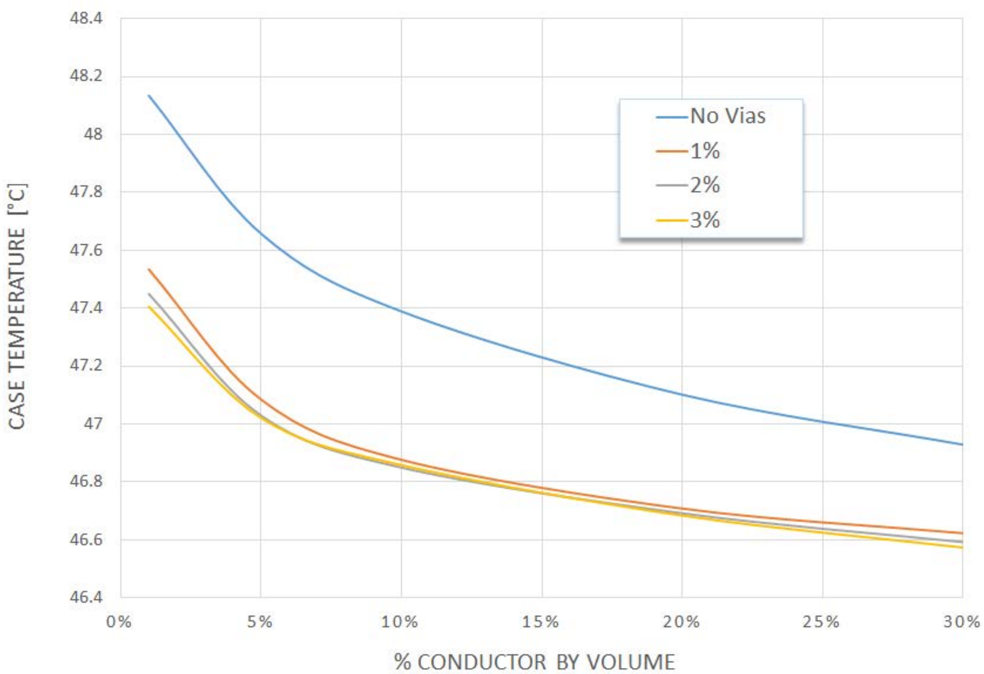
- With Heat Spreader
- Without Heat Spreader



Design Study: PCB Effective Thermal Conductivity

PCB Effective Thermal Conductivity

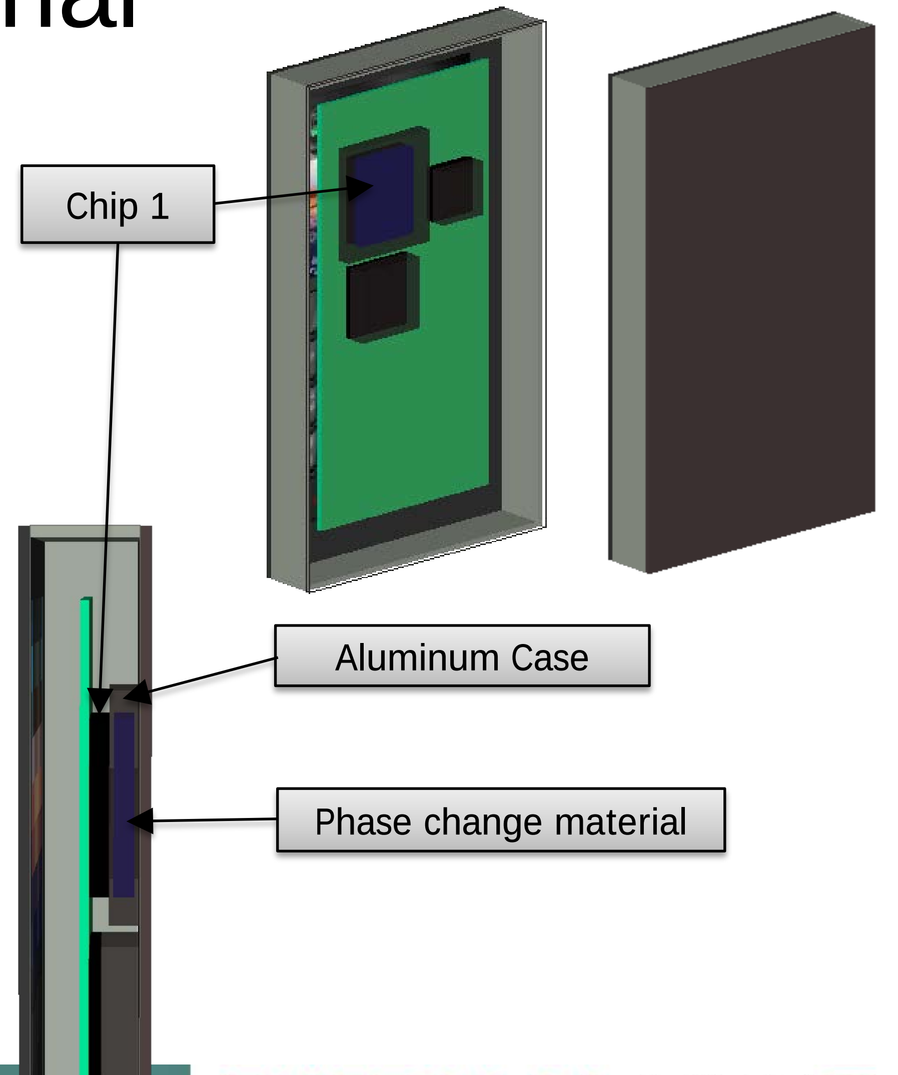




- Through-Plane: biggest gain from “No Vias” to 1%
- In-Plane: linear decrease in case temperature after 10%
- No significant benefit in case temperature

Design Study: Phase Change Material

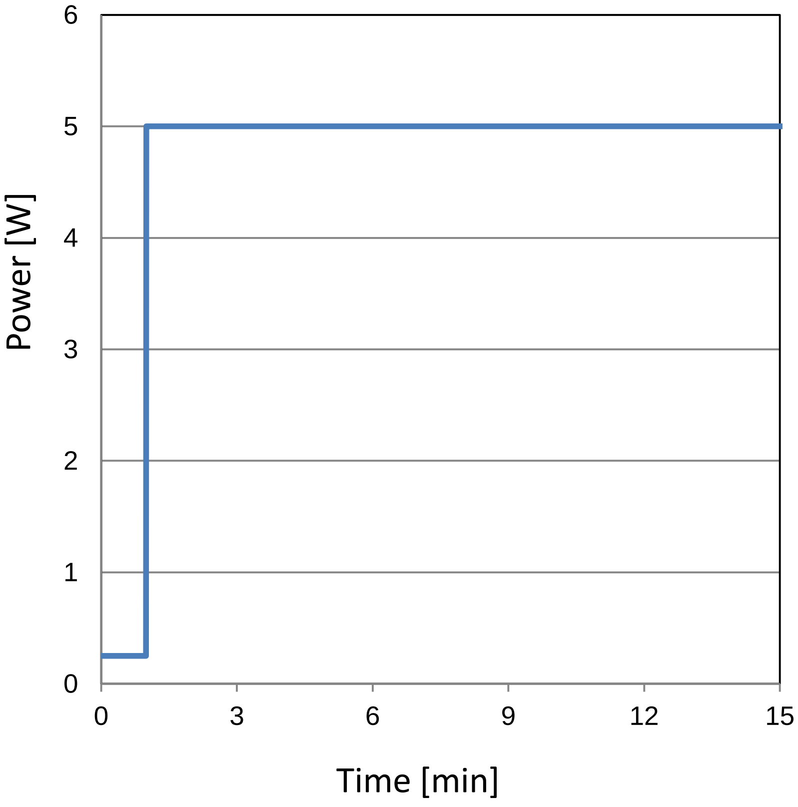
- At steady state the maximum case temperature is:
  - 32.5°C when chip 1 is in an idle state [0.25W]
  - 49.0°C when chip 1 under maximum load [5W]
- At maximum load:
  - How long it would take reach 41°C case temperature
  - Is there any benefit with using Phase Change Material (PCM)



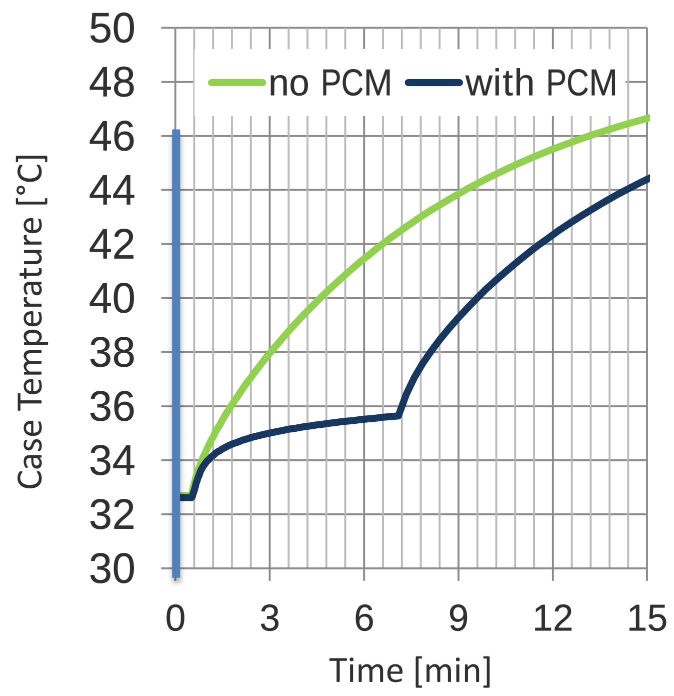
Use Case 1: Streaming Video

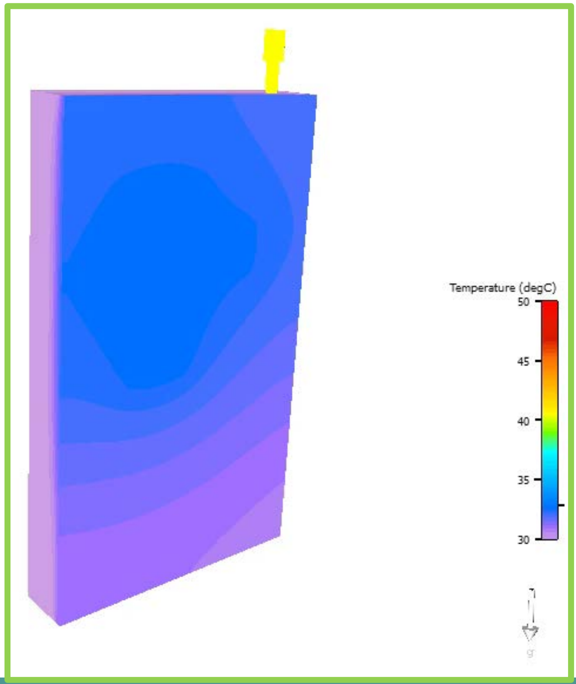
- To understand the benefit of the PCM consider the following use case

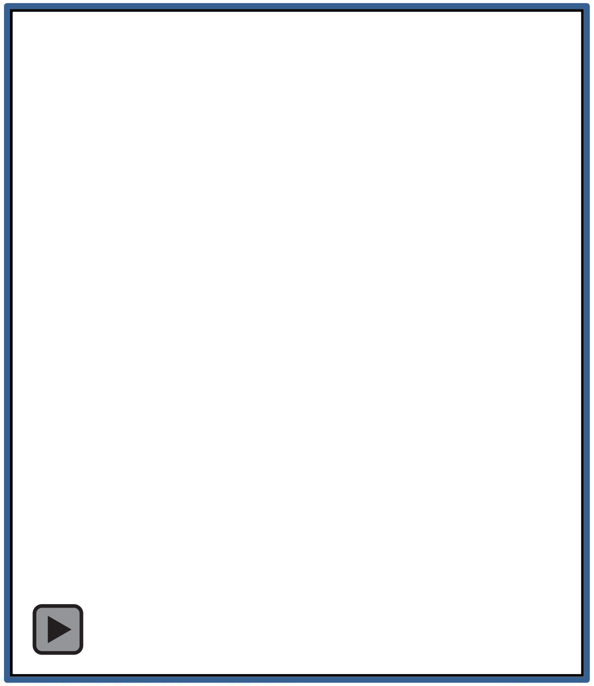
Streaming Video power profile



Results: Streaming Video

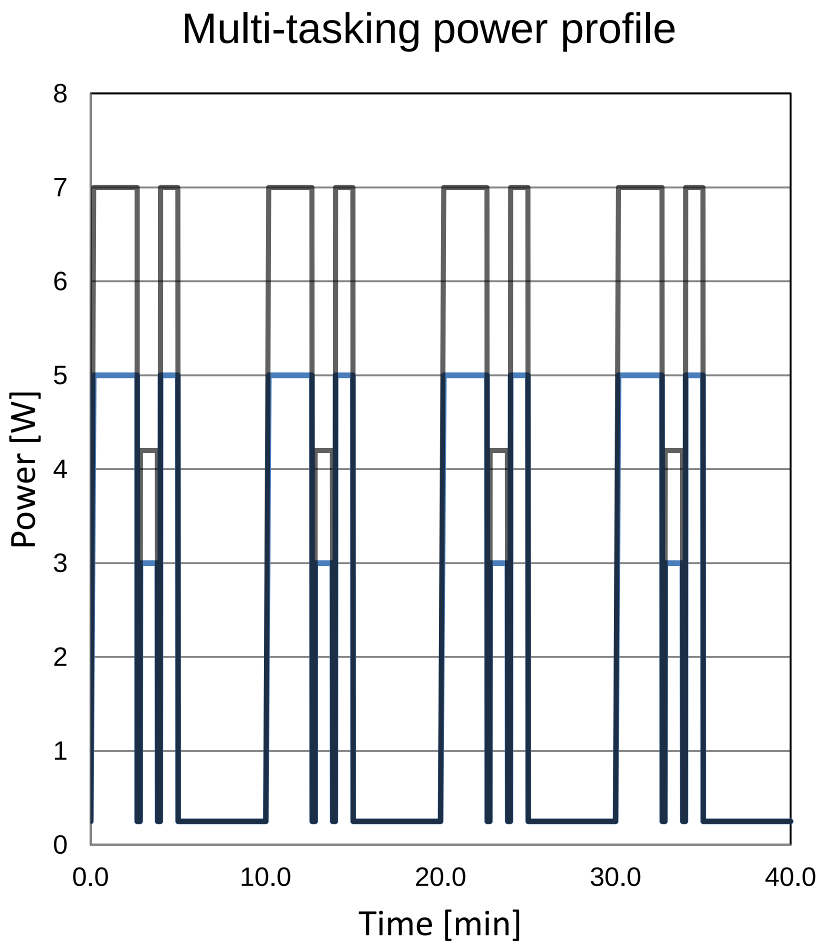






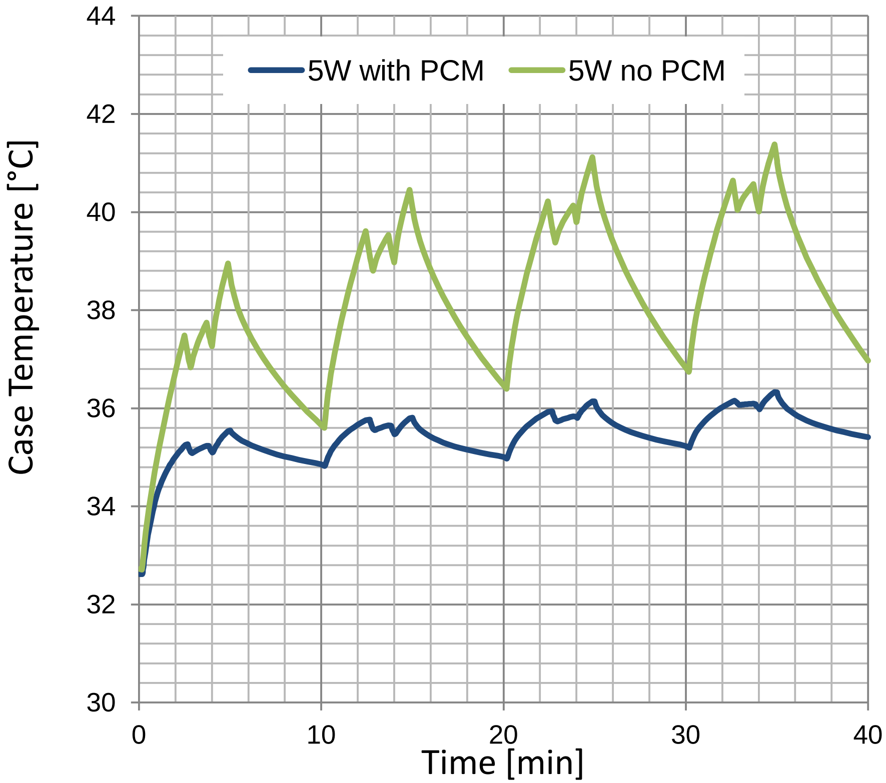
Use Case 2: Multi-Tasking

- Consider a multi-tasking power profile with peak powers of 5W and 7W

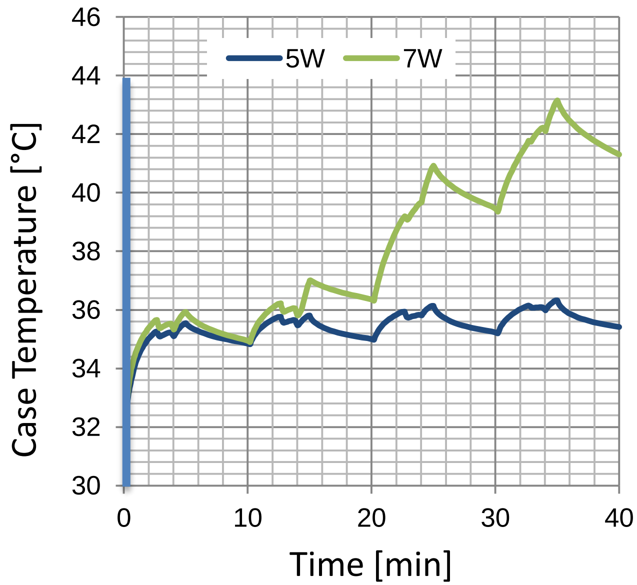


Results: PCM with Multi-Tasking

- With the PCM the case temperature never exceeds 41°C



Results: PCM with Peak Power



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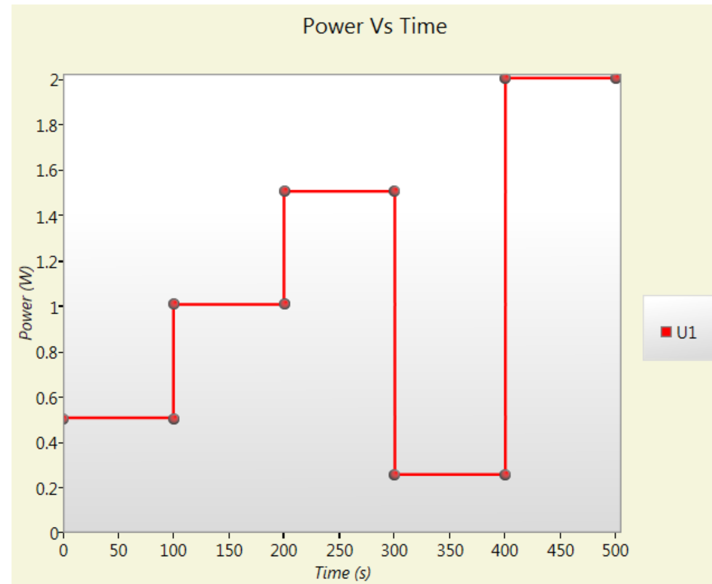
Temperature Management

- User Experience-When to throttle performance:
  - Too soon and the device will seem slow or video quality will seem inferior
  - Too late and the device will seem too hot (or cause injury)

Temperature Control with Sensors

- Use board temperature sensors as proxy for case temperature
- Design process:
  - Add multiple board sensors
  - Step thermal power based on operational mode
  - Track sensor and hotspot temperature response

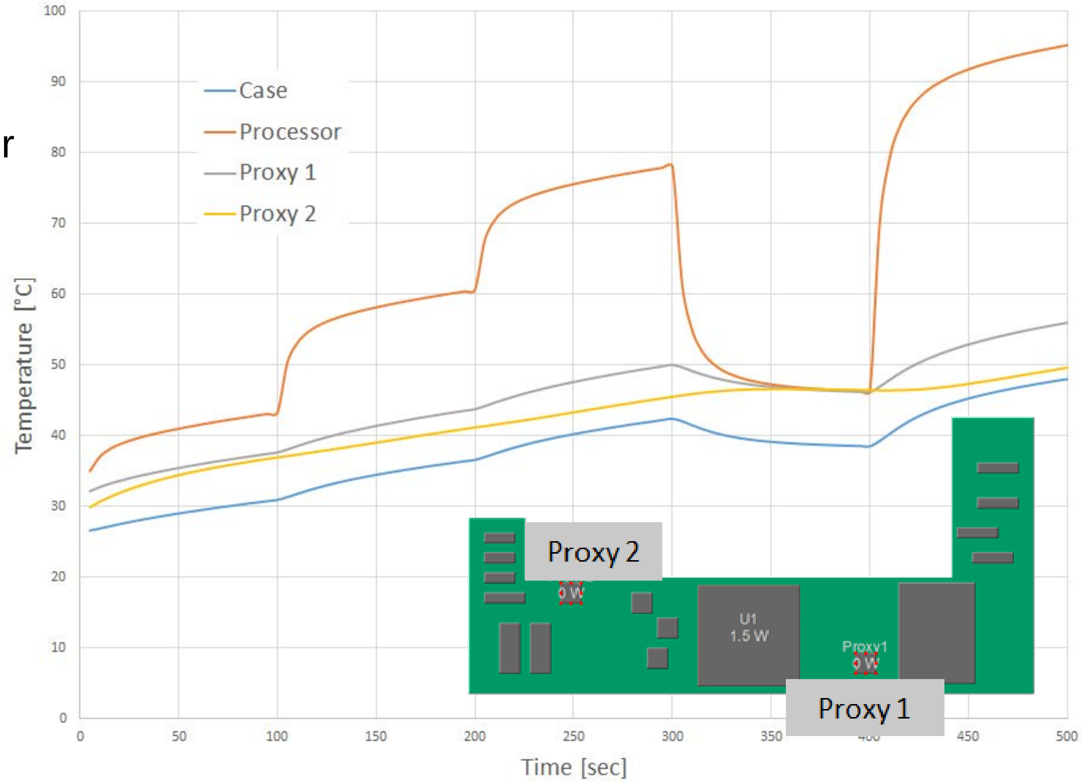


Start Time (s)	Duration (s)	Mode	Transition Time (s)		
0	100	1x	0.05	+	-
100.05	100	2x	0.05	+	-
200.1	100	3x	0.05	+	-
300.15	100	.5x	0.05	+	-
400.2	100	4x	0.05	+	-

Source: Cathy Biber, Ph.D., Sensor Placement for Surface Temperature Control in Thin Mobile Form Factors, *31st IEEE SEMI-THERM Symposium*

Temperature Control with Sensors

- Ideally a 1:1 relationship between case temperature and proxy
- Proxy 1 a near constant DT from case temperature
- Proxy 2 lags and is has a shallower response



Source: Cathy Biber, Ph.D., Sensor Placement for Surface Temperature Control in Thin Mobile Form Factors, *31st IEEE SEMI-THERM Symposium*

Summary

- Mobile devices have unique thermal design issues
  - Maximum Outer Case Temperature is primary design goal, opposed to the typical maximum junction temperature
  - Perceived performance is more critical than actual performance
- Thermal Design limited to strategic isolation and heat spreading
- Some benefit might be achieved with the use of phase change materials
- Temperature Management is critical to maintain device performance while limiting outer surface temperatures

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Thanks for attending!

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