AM574x thermal considerations

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ABSTRACT

This application report discusses the thermal performance of the Sitara™ AM574x series processors. The data presented demonstrates the effects of different thermal management strategies in terms of processor junction temperature and power consumption across MPU loading and ambient temperature.

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1 Overview

In this experiment, an internal AM574x board is used to gather thermal data with different processor loading and ambient temperature. Ambient temperature is controlled with a programmable environmental chamber.

The collected data can be utilized to correlate the thermal performance of the processor and power consumption at a given processor load and junction temperature, based on ambient temperature and thermal management.

Tests were repeated with the following thermal management:

- Bare package (no heatsink)
- Low-cost heatsink (31-mm x 31-mm x 19.5-mm, #ATS-54310R-C1-R0)
- Low-cost heatsink + Fan (5 V, 9500 RPM, 4.9 CFM, #MC30060V1-000U-A99)

2 Important Notes

The environmental chamber used to collect this data circulates air internally to maintain homogeneous internal temperature, and does not accurately simulate the environment on the bench or end product. This is important to consider in passive cooling applications where air circulation can significantly impact PCB, package, and heatsink power dissipation efficiency.

The data presented in this test is gathered with a typical device, representing nominal silicon process and leakage. Thermal performance and power consumption can vary significantly due to process variation. Extra margin must be designed in to account for worst case process variation (leakage).

3 Test Overview

The following CPU loading schemes are characterized with the internal AM574x board for this report.

3.1 OS Idle

The AM574x processor is idling after booting the out-of-box configuration of Processor SDK Linux® v05.02.00. No display was connected to the AM574x board. MPU, GPU, and IVA cores are powered but automatically clock gated while the DSP and IPU cores are both power and clock gated.

3.2 Dhrystone

Dhrystone is a single-threaded benchmark, capable of utilizing approximately 100% of one Arm® Cortex®-A15 core. Dhyrstone is included in the TI Processor SDK. Tests are conducted with the A15 running at 1.0 GHz (OPP_NOM) and 1.5 GHz (OPP_HIGH).

3.3 Temperature Measurement

Reported temperature data is measured by on-die sensors to the approximate actual junction temperature. Temperature for each use-case is measured after soaking for five minutes. Under lab conditions, it is determined a five minute period allows the processor to reach stable temperature.

The TI Processor SDK provides Linux drivers for these sensors, and can be queried from the command-line. For example:

```
# cat /sys/class/thermal/thermal_zone0/temp
71800
```

3.4 OPP Definitions

Operating performance points (OPP) levels define a max frequency per fixed voltage level in each voltage domain. Table 1 lists the frequency of each subsystem per OPP for the AM574x processor.

Dynamic Voltage Frequency Scaling (DVFS) refers to a software technique where the system-on-chip (SoC) supplies with AVS support are changed from one OPP level (voltage and frequency pair) to another to either adapt to a changing work-load, or to avoid device operation outside of desired temperature bounds.

This SoC only supports DVFS on the MPU domain. For DSP and GPU domains, the OPP levels must be set during boot by the initial bootloader. Ensure that the selected OPP level meets the needs of the application and all thermal testing is conducted at the desired OPP level.

Table 1. Supported OPP vs Max Frequency

Voltage Domain	Clock Domain	OPP_NOM Maximum Frequency (MHz)	OPP_OD Maximum Frequency (MHz)	OPP_HIGH Maximum Frequency (MHz)
VD_MPU	MPU_CLK	1000	1176	1500
VD_DSP	DSP_CLK	600	700	750
	EVE_FCLK	535	650	650
VD_IVA	IVA_GCLK	388.3	430	532
VD_GPU	GPU_CLK	425.6	500	532
VD_CORE	DDR3 / DDR3L	667 (DDR3-1333)	N/A	N/A
	CORE_IPUx_CLK	212.8	N/A	N/A
	L3_CLK	266	N/A	N/A
VD_RTC	RTC_FCLK	0.034	N/A	N/A

4 Data and Results

This section contains the raw data and graphs of the test experiments described above. All data is gathered running the latest Linux Processor SDK. All tests are conducted without an external display installed.

4.1 OPP Settings and Linux Thermal Framework

Tests are conducted with Processor SDK 04.02.00 at following OPP levels:

Default OPP Levels			
MPU	**GPU**	**DSP**	**IVA**
NOM	HIGH	HIGH	HIGH

The MPU domain OPP defaults to NOM when idle and increases to HIGH when under load. OPP levels for DSP and IVA cores can be changed but that must be done by editing the U-Boot defconfig file with the desired OPP level and recompiling.

Applicable to the AM574x, the Linux kernel on this device uses the CPUFreq driver to support multiple OPPs for the MPU domain and dynamically changes between them. As such, a desired maximum frequency must be set if you are seeking power consumption at a frequency lower than the maximum.

Additionally, the Linux thermal framework needs to be disabled, otherwise, the maximum frequency is reduced as the MPU heats up to prevent thermal shutdown. This must only be done for data gathering purposes when the junction temperature exceeds the levels defined in the device tree and is not recommended for a production system.

4.2 Power and Thermal Chamber Measurements

The tables shown in the following sections contain power consumption and junction temperature measured running OS Idle and Dhrystone single-core use-cases at different controlled ambient temperatures with and without an attached heatsink. This silicon process type is nominal. Dhrystone tests are repeated with MPU at each supported OPP.

Junction temperature and power reported in the following sections are sampled at the same time, and are presented in separate tables to aid comprehension.

4.3 OS Idle at OPP_NOM

OPP Levels			
MPU	GPU	DSP	IVA
NOM	HIGH	HIGH	HIGH

Thermal Management	Ta (°C)				
	25	45	60	75	90
No Heatsink (°C)	39	59.8	78	100.8	
Heatsink (°C)	32.6	53.3	69.8	85.6	102.2
Heatsink + Fan (°C)	31	49.6	66.3	81.8	99.6

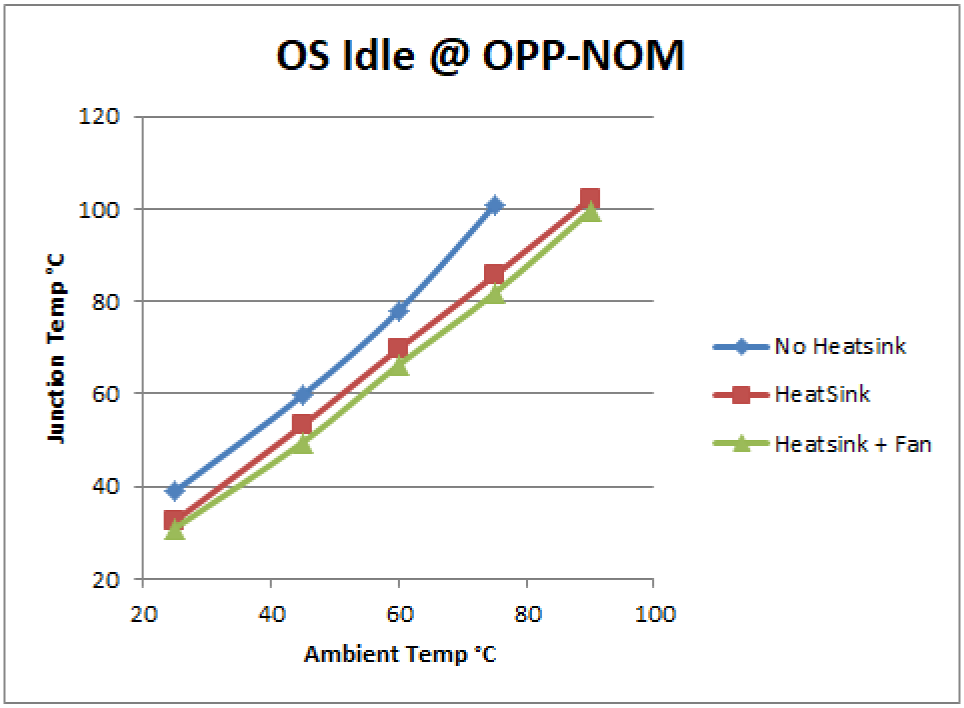

Figure 1. OS Idle - OPP_NOM (Junction Temp vs Ambient Temp)

Thermal Management	Ta (°C)				
	25	45	60	75	90
No Heatsink (mW)	2319.1	2776.4	3427.2	4744	
Heatsink (mW)	2212	2621.4	3124.9	3811.9	4877.3
Heatsink + Fan (mW)	2208.1	2518	2978.5	3641.7	4703.1

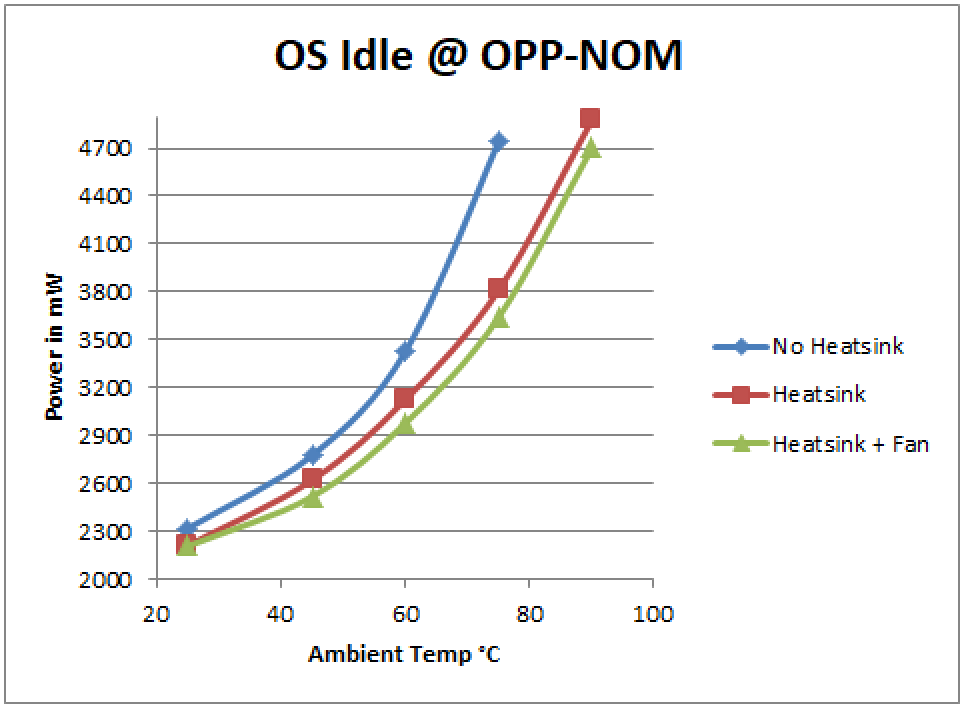

Figure 2. OS Idle - OPP_NOM (Power Consumption vs Ambient Temp)

4.4 Dhrystone 1 Core at OPP_NOM

OPP Levels			
MPU	**GPU**	**DSP**	**IVA**
NOM	HIGH	HIGH	HIGH

Thermal Management	Ta (°C)				
	25	**45**	**60**	**75**	**90**
No Heatsink (°C)	44.2	65	85.9	112	
Heatsink (°C)	35.2	55.6	71.5	88.5	106.8
Heatsink + Fan (°C)	33	52.3	68.4	85.5	103.2

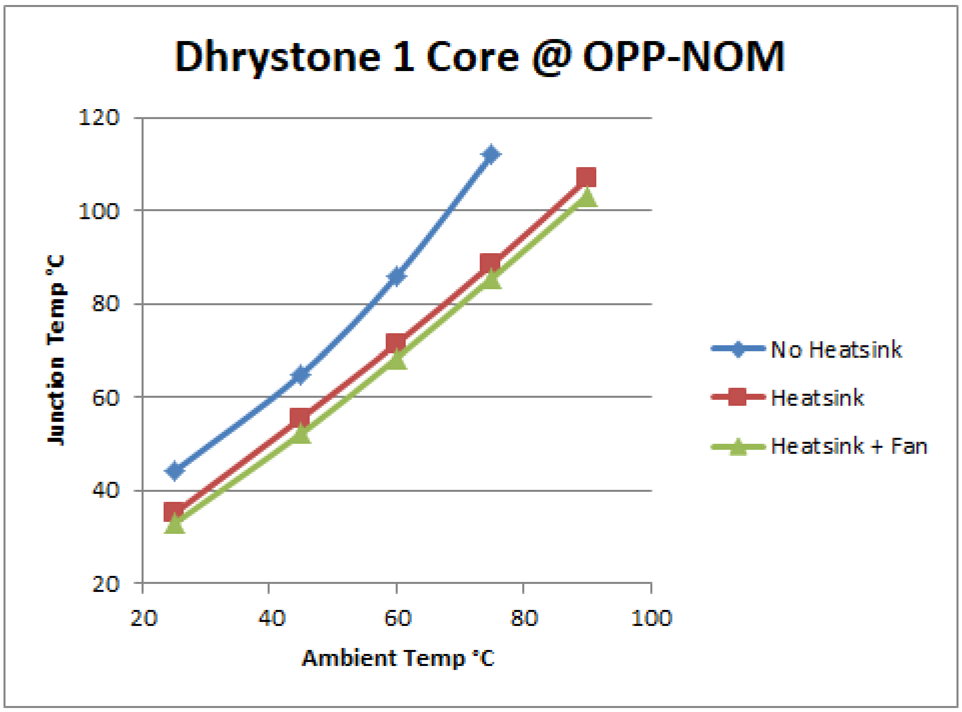

Figure 3. Dyrystone (Core 1) at OPP_NOM (Junction Temp vs Ambient Temp)

Thermal Management	Ta (°C)				
	25	45	60	75	90
No Heatsink (mW)	3157.5	3707.1	4610.1	6366.7	
Heatsink (mW)	3010.6	3448.8	3952.1	4778.4	6071.4
Heatsink + Fan (mW)	2974.7	3399.1	3916	4614.9	5777.2

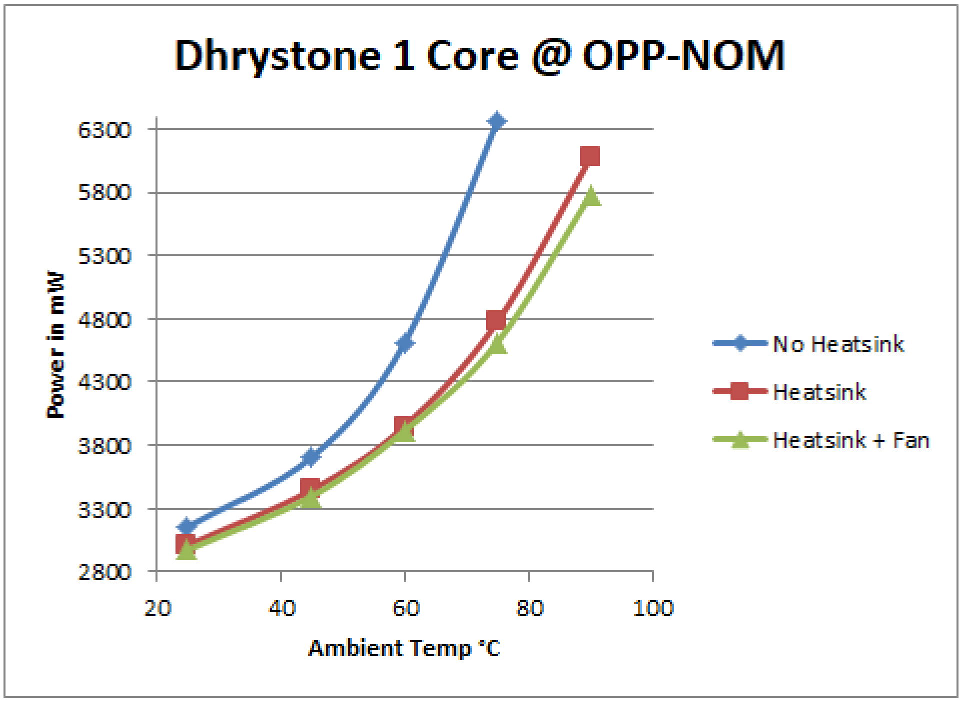

Figure 4. Dyrystone (Core 1) at OPP_NOM (Power Consumption vs Ambient Temp)

4.5 Dhrystone 2 Core at OPP_NOM

OPP Levels			
MPU	**GPU**	**DSP**	**IVA**
NOM	HIGH	HIGH	HIGH

Thermal Management	Ta (°C)				
	25	**45**	**60**	**75**	**90**
No Heatsink (°C)	50.5	73.3	93.4		
Heatsink (°C)	38.2	58.4	75	91.8	111.4
Heatsink + Fan (°C)	35.3	54.8	71.5	88	105.8

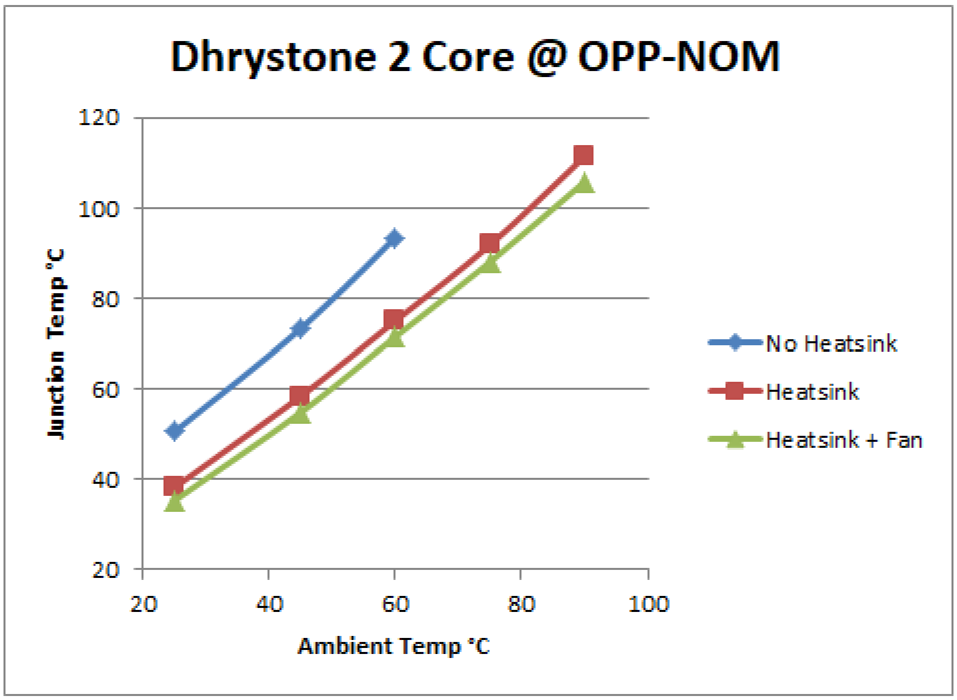

Figure 5. Dyrystone (Core 1 and Core 2) at OPP_NOM (Junction Temp vs Ambient Temp)

Thermal Management	Ta (°C)				
	25	**45**	**60**	**75**	**90**
No Heatsink (mW)	4111.4	4869.1	5966		
Heatsink (mW)	3852.5	4303.7	4916.3	5819.6	7247.3
Heatsink + Fan (mW)	3849.7	4276.2	4825.1	5592.9	6827.6

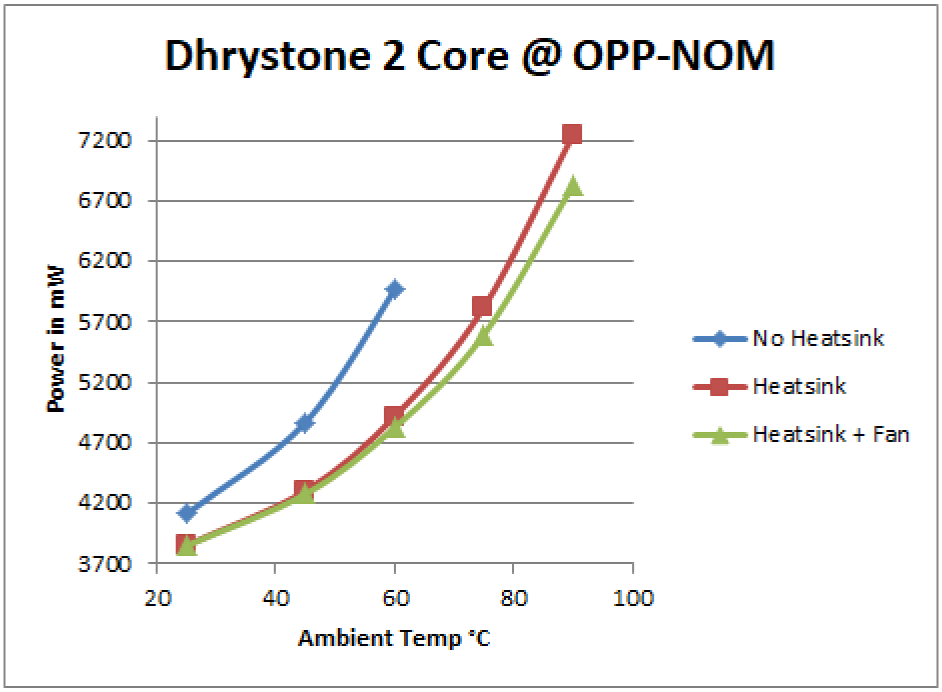

Figure 6. Dyrystone (Core 1 & Core 2) at OPP_NOM (Power Consumption vs Ambient Temp)

4.6 Dhrystone 1 Core at OPP_HIGH

OPP Levels			
MPU	**GPU**	**DSP**	**IVA**
HIGH	HIGH	HIGH	HIGH

Thermal Management	Ta (°C)				
	25	**45**	**60**	**75**	**90**
No Heatsink (°C)	54.2	81.2			
Heatsink (°C)	38.6	60.6	77.5	96	
Heatsink + Fan (°C)	36.4	57.7	73.9	91.3	

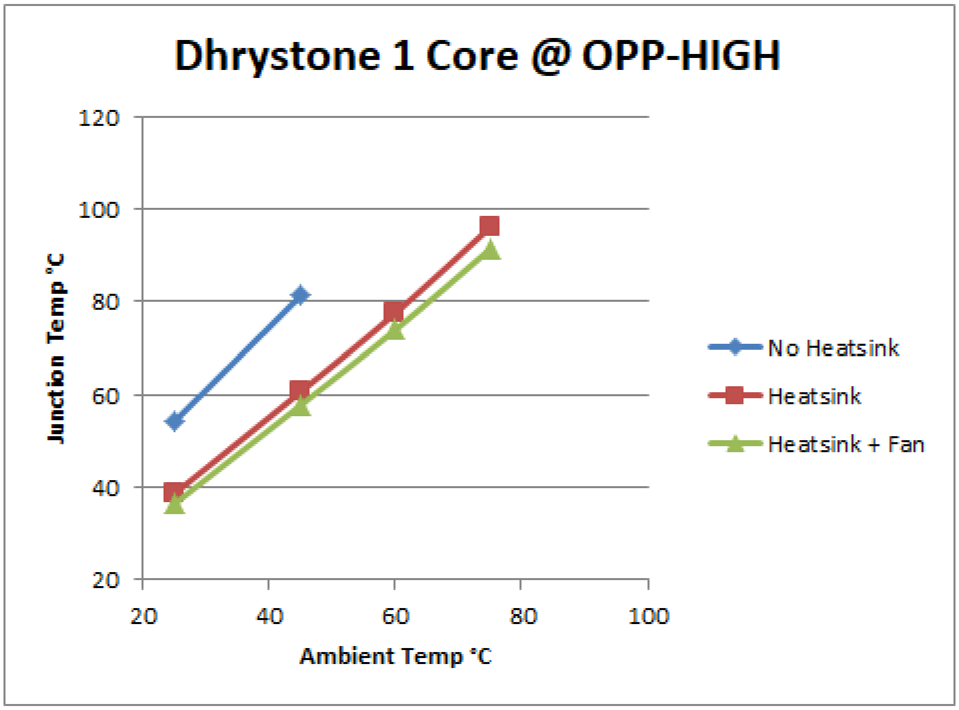

Figure 7. Dyrystone (Core 1) at OPP_HIGH (Junction Temp vs Ambient Temp)

Thermal Management	Ta (°C)				
	25	45	60	75	90
No Heatsink (mW)	4949.6	6362			
Heatsink (mW)	4397.9	5151.9	6007.6	7521	
Heatsink + Fan (mW)	4361.2	5041.5	5803.9	7063.7	

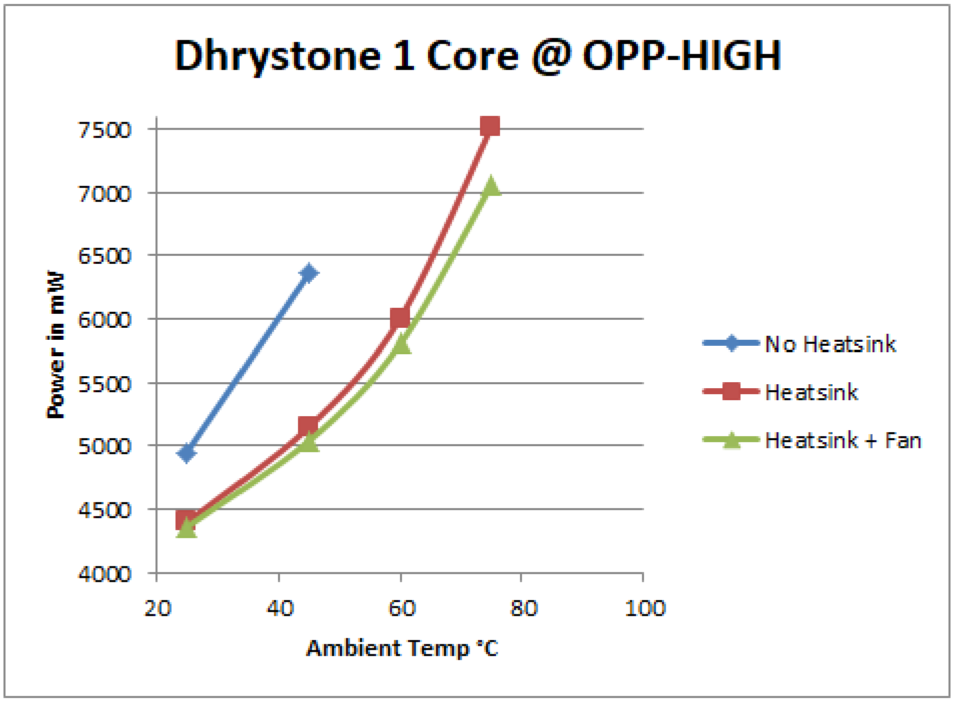

Figure 8. Dyrystone (Core 1) at OPP_HIGH (Power Consumption vs Ambient Temp)

4.7 Dhrystone 2 Core at OPP_HIGH

OPP Levels			
MPU	**GPU**	**DSP**	**IVA**
HIGH	HIGH	HIGH	HIGH

Thermal Management	Ta (°C)				
	25	**45**	**60**	**75**	**90**
No Heatsink (°C)	68.4	102.4			
Heatsink (°C)	44.6	66.4	84.5	104.4	
Heatsink + Fan (°C)	40.8	62.2	79	97.5	

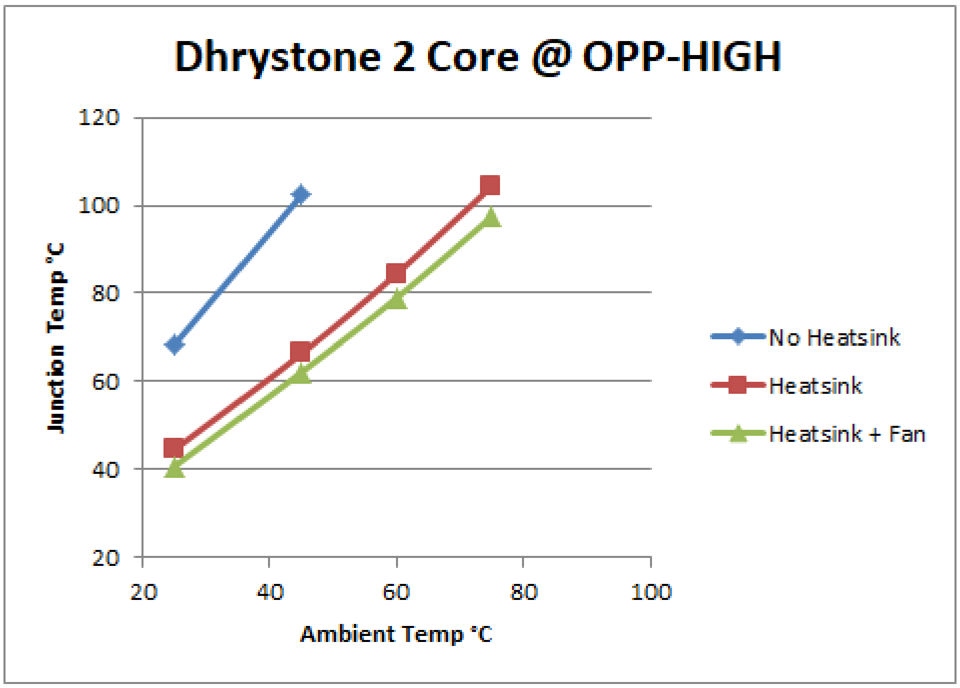

Figure 9. Dyrystone (Core 1 & Core 2) at OPP_HIGH (Junction Temp vs Ambient Temp)

Thermal Management	Ta (°C)				
	25	45	60	75	90
No Heatsink (mW)	7311.6	9999.8			
Heatsink (mW)	6269.4	7156.7	8338.7	10297.3	
Heatsink + Fan (mW)	6162.4	6958	7938.4	9487.3	

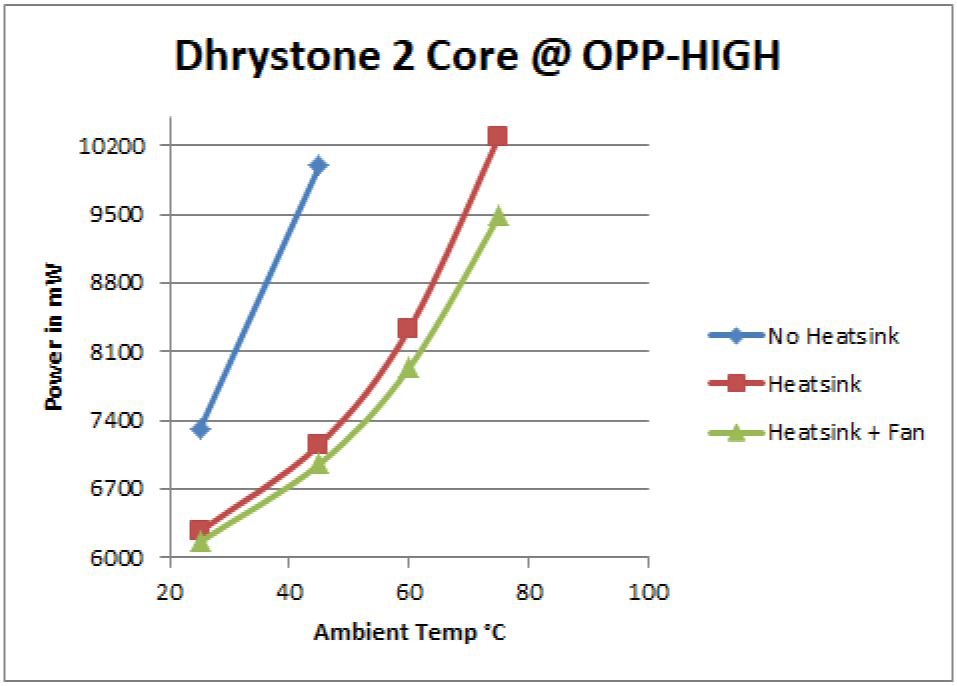

Figure 10. Dyrystone (Core 1 & Core 2) at OPP_HIGH (Power Consumption vs Ambient Temp)

5 References

- To learn more about thermal management, visit http://www.ti.com/thermal
- Texas Instruments: *Thermal design guide for DSP and ARM application processors*
- Thermal models can be found in the Models section of Tools and Software in the product folder: http://www.ti.com/product/AM5748/toolssoftware

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