AN12310

Thermal Management Unit Usage

Rev. 0 — 27 April 2022 Application Note

Contents

1 Overview

This application note introduces the LS1xxxx and LS2xxxx devices Thermal Management Unit (TMU). It covers the topics, such as explanation of NXP TMU functional blocks and how to operate, program, and configure them. Later the SDK 2.0 solution is described followed by test examples and usage cases.

2 TMU operation model

Figure 1 shows the overall operation concept of the TMU.

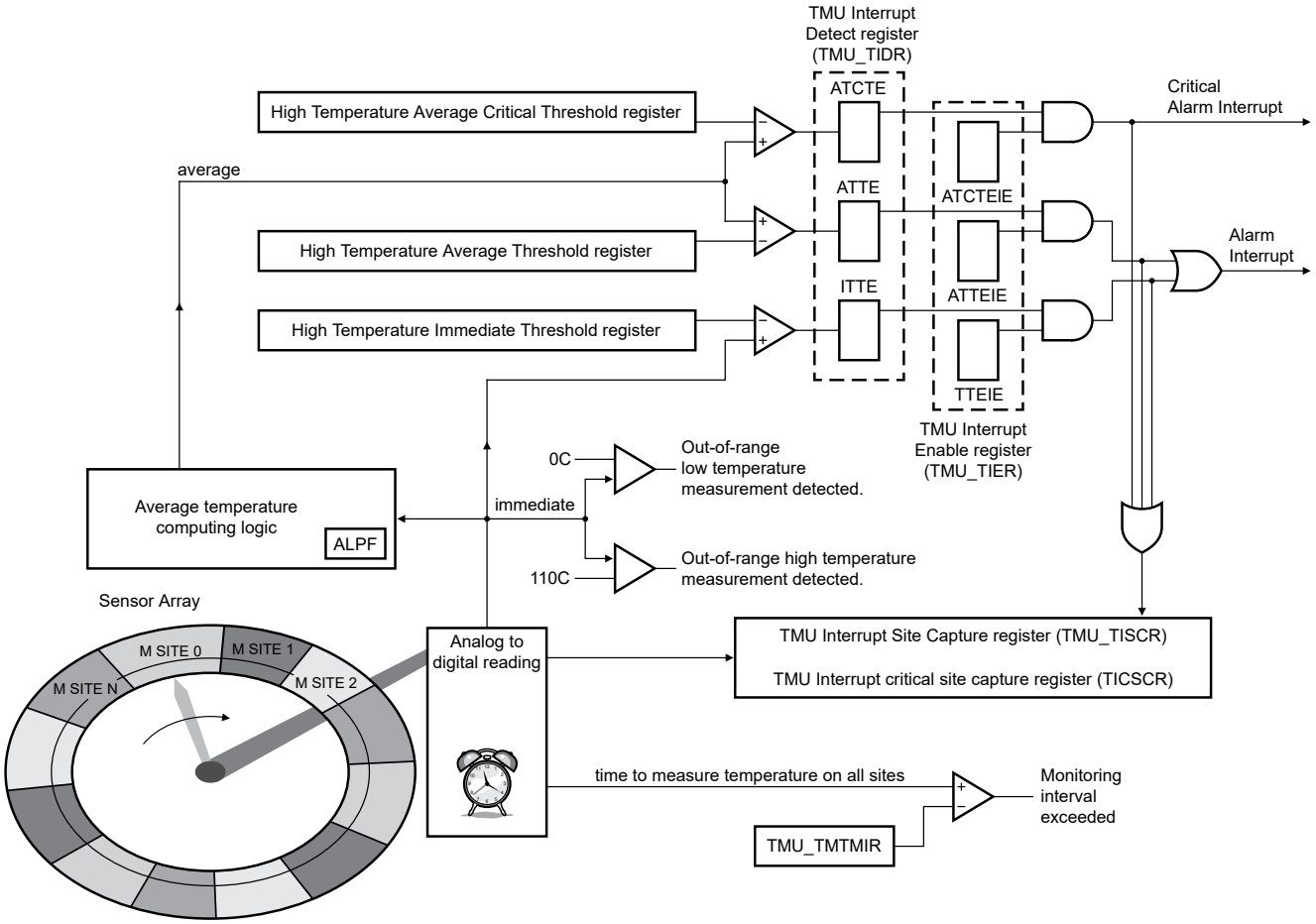

Figure 1. TMU operation model

2.1 Sensor array

Each LSxxxx chip has several temperature sensors strategically positioned under major logic block. For example, LS1043 has 5 sensors as shown in Table 1.

Table 1. Sensor placement

Temperature sensor ID	Placement
0	Near DDR controller
1	Near SerDes
2	Near Frame manager
3	Near Arm® Cortex®-A53 core
4	SEC

User can enable each site by setting a bit in the TMR[MSITE] bits. For example, to enable sensors near A53 and DDR controller, MSITE[0-4] should be 5'b10010. Thus, with monitoring mode disabled, ME = 0 and ALPF = 2'b00, the TMR bit settings are shown in the figure below.

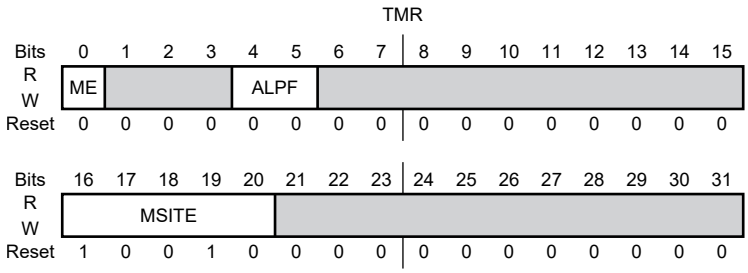

Figure 2. Sensor bits

The sensors are selected periodically and the temperature computation takes some time for each temperature sensor. If the periodic measurement interval divided by the number of enabled sensors is more than the time required to compute temperature, then TMU goes to the low-power mode until next sensor interval-starting time. On the other hand, if it is less than the computation time then the "monitoring interval exceeded" error bit is set in the TSR[MIE].

2.2 Analog to digital reading

The captured reading by the Analog to digital converter is passed to the following:

- Average temperature computing logic
- Instantaneous out of range high/low comparators
- High temperature-immediate threshold comparison logic
- Instantaneous reading registers
- Monitoring and reporting logic

If the instantaneous reading goes beyond or below 110 °C or 0 °C, then the TSR[ORL, ORH] bits are set but no interrupt is generated.

The average temperature computing logic presents an average reading as a function of the previous readings multiplied by a factor set by TMR[ALPF] parameter such that: Average temperature = ALPF x Current_Temp + (1 - ALPF) x Average_Temp.

If no previous average temperature is valid, current temperature is used. For proper operation, the ALPF optional values are 1.0, 0.5, 0.25, and 0.125. If ALPF is one, then the average temperature is the current instantaneous reading.

Figure 3 and Figure 4 shows that the theoretical filtering action the ALPF values impacts on a two different "hypothetical" instantaneous reading profiles.

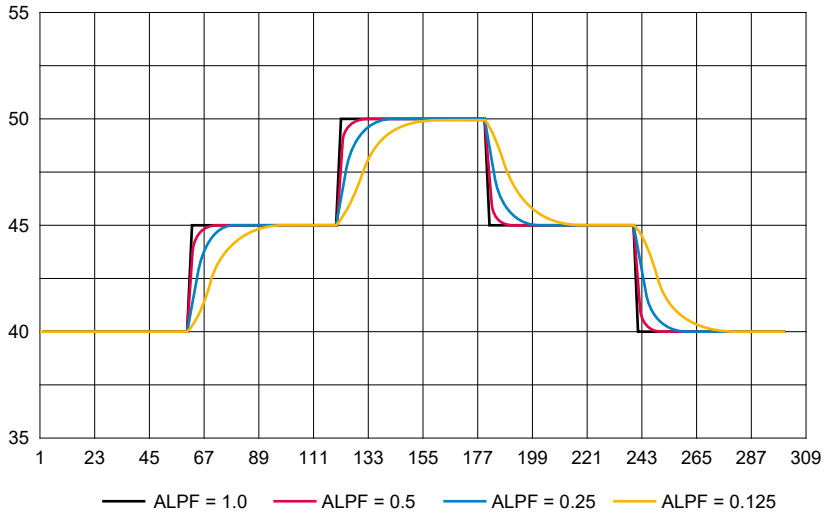

Figure 3. Immediate temperature vs average temperature example 1

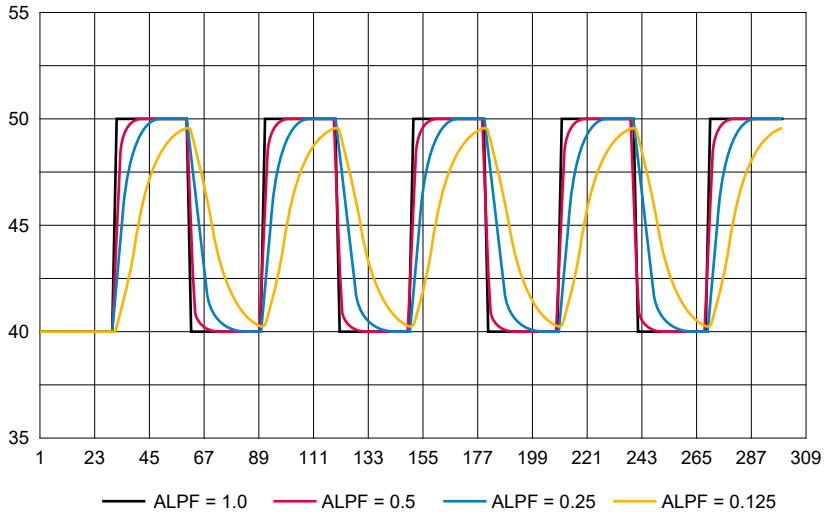

Figure 4. Immediate temperature vs average temperature example 2

The average temperature then is compared against two stored threshold values in the following:

- High temperature average critical threshold register
- High temperature average threshold register

While the instantaneous current temperature reading is also compared against the value stored in the following:

- High temperature-immediate threshold register

If the average or instantaneous temperature value exceeds the limit values stored in the threshold registers, the TMU interrupt detect register TIDR[ITTE, ATTE, ATCTE] bits are set.

Besides, detecting the set, if the corresponding TMU interrupt enable register bits TIER[ITTEIE, ATTEIE, ATCTEIE] are enabled. A critical interrupt is generated if bit TIER [ATCTE] is set, or an alarm interrupt is generated if TIER [ITTE], or TIER [ATTE] is set given that their corresponding TIDR bits were set too.

The interrupt handler tells which sensor site temperature reading has exceeded the threshold value by reading the TMU interrupt site capture register TISCR or the TMU interrupt critical site capture register.

3 Initialization procedure

In general, customers are given initialization data in the chip reference manual and SW driver use them as is. The TMU had internal array that holds calibration data and is structured in four ranges as listed in Table 2.

Table 2. Initialization data array

TTRnCR region	Array address to TTCFGR	Array data to TSCFGR
TTR0CR, 12 points at 0 °C. Each row represents an increment by 4	0x00000000	0x00000023
	0x00000001	0x0000002A
	0x00000002	0x00000031
	0x00000003	0x00000037
	0x00000004	0x0000003E
	0x00000005	0x00000044
	0x00000006	0x0000004B
	0x00000007	0x00000051
	0x00000008	0x00000058
	0x00000009	0x0000005E
	0x0000000A	0x00000065
	0x0000000B	0x0000006B
TTR1CR, 10 points at 42 °C. Each row represents an increment by 4	0x00010000	0x00000023
	0x00010001	0x0000002B
	0x00010002	0x00000033
	0x00010003	0x0000003B
	0x00010004	0x00000043
	0x00010005	0x0000004B
	0x00010006	0x00000054
	0x00010007	0x0000005C
	0x00010008	0x00000064
	0x00010009	0x0000006C
TTR2CR, 7 points at 76 °C. Each row represents an increment by 4	0x00020000	0x00000021
	0x00020001	0x0000002C
	0x00020002	0x00000036
	0x00020003	0x00000040
	0x00020004	0x0000004B

Table continues on the next page...

Table 2. Initialization data array (continued)

TTRnCR region	Array address to TTCFGR	Array data to TSCFGR
	0x00020005	0x00000055
	0x00020006	0x0000005F
TTR3CR, 8 points at 98 °C. Each row represents an increment by 4	0x00030000	0x00000013
	0x00030001	0x0000001D
	0x00030002	0x00000028
	0x00030003	0x00000032
	0x00030004	0x0000003D
	0x00030005	0x00000047
	0x00030006	0x00000052
	0x00030007	0x0000005C

A simple plot of the previous tabulated data is shown below.

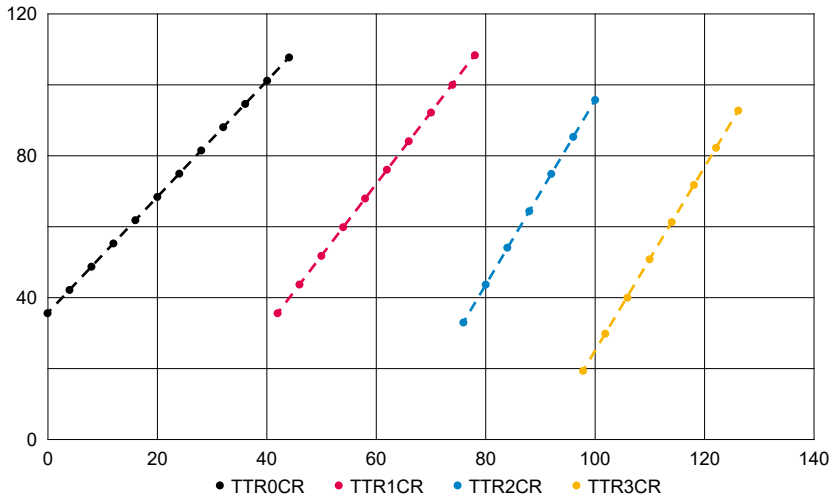

Figure 5. Initialization data plots

The figure below illustrates the calibration data structure.

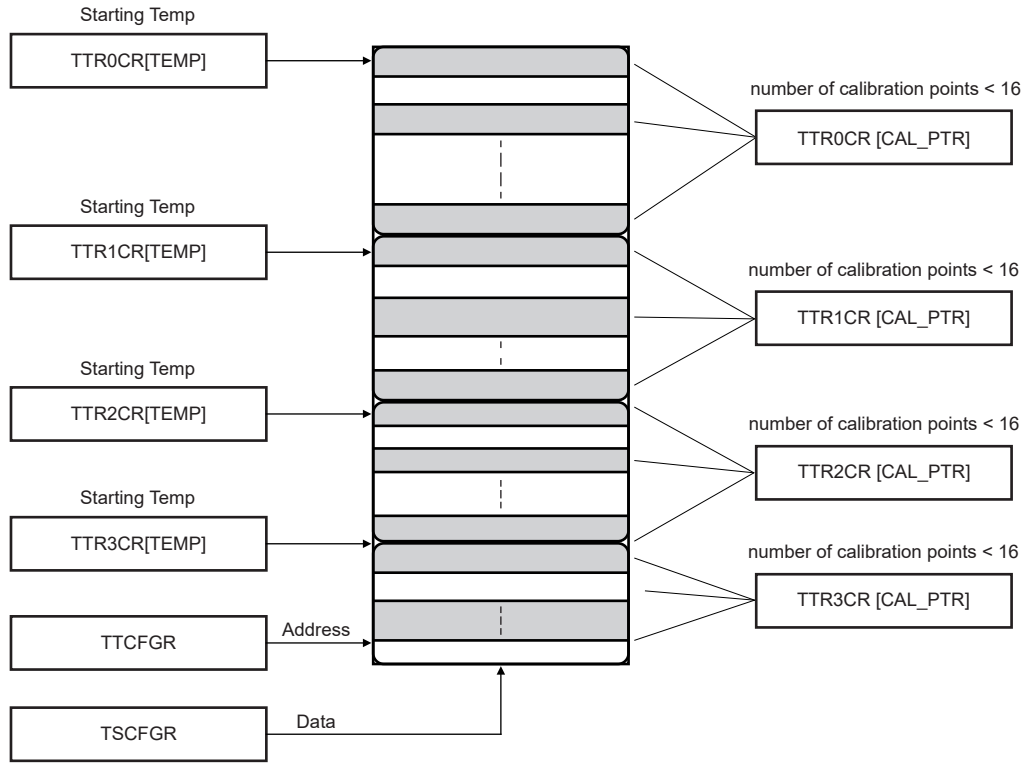

Figure 6. Calibration data structure

In the above figure, the bulk of array is a 64-entry arranged in 4 sixteen blocks, where each TTRnCR register carries information about this 16 entries block, namely the starting temperature of the first entry and the total number of entries -1, that are programed out of 16 entries. Users typically know the total number based on the information provided by the chip reference manual. For example, in the LS1043A Reference Manual we see the below starting temperatures and number of points which results in the corresponding TTRnCR shown in Table 3.

Table 3. Temperature calibration points

12 points => 0xB	Starts from 0C => 0x0	TTR0CR=0x000B0000
10 points => 0x9	Starts at 42C => 0x2A	TTR1CR=0x0009002A
7 points => 0x6	Starts at 76C => 0x4c	TTR2CR=0x0006004C
8 points => 0x7	Starts at 98C => 0x62	TTR3CR=0x00070062

The process for programming the calibration table is described below.

1. Disable the monitoring mode, TMR[ME]=0 (default).
2. Program TTR0CR=0x000B0000, TTR1CR=0x0009002A, TTR2CR=0x0006004C, and TTR3CR=0x00070062.
3. Write the temperature configuration register (TTCFGR).
4. Write the sensor configuration register (TSCFGR).
5. Repeat steps 3 to 4 for all temperatures as defined in Table 3.

Table 4. Example U-Boot commands that initialize TMU

Example of a U-Boot series of command that initializes TMU	Comments
#=====Load init table === #====================== mw 0x1f00000 0x0 mw 0x1f00f10 0x00000b00 mw 0x1f00f14 0x2a000900 mw 0x1f00f18 0x4c000600 mw 0x1f00f1c 0x62000700 #====================== #== TTR0CR, 12 points at 0°C === #{0x00000000, 0x00000023} mw 0x1f00080 0x00000000 mw 0x1f00084 0x23000000 #{0x00000001, 0x0000002A} mw 0x1f00080 0x01000000 mw 0x1f00084 0x2a000000 #{0x00000002, 0x00000031} mw 0x1f00080 0x02000000 mw 0x1f00084 0x31000000 #{0x00000003, 0x00000037} mw 0x1f00080 0x03000000 mw 0x1f00084 0x37000000 #{0x00000004, 0x0000003E} mw 0x1f00080 0x04000000 mw 0x1f00084 0x3e000000 #{0x00000005, 0x00000044} mw 0x1f00080 0x05000000 mw 0x1f00084 0x44000000 #{0x00000006, 0x0000004B} mw 0x1f00080 0x06000000 mw 0x1f00084 0x4b000000 #{0x00000007, 0x00000051} mw 0x1f00080 0x07000000 mw 0x1f00084 0x51000000	Notice that there is endianness byte swap of the word contents when we type U-Boot command

Table continues on the next page...

Table 4. Example U-Boot commands that initialize TMU

Example of a U-Boot series of command that initializes TMU	Comments
#{0x00000008, 0x00000058} mw 0x1f00080 0x08000000 mw 0x1f00084 0x58000000 #{0x00000009, 0x0000005E} mw 0x1f00080 0x09000000 mw 0x1f00084 0x5e000000 #{0x0000000A, 0x00000065} mw 0x1f00080 0x0a000000 mw 0x1f00084 0x65000000 #{0x0000000B, 0x0000006B} mw 0x1f00080 0x0b000000 mw 0x1f00084 0x6b000000 #================================== #===TTR1CR, 10 points at 42°C==== #{0x00010000, 0x00000023} mw 0x1f00080 0x00000100 mw 0x1f00084 0x23000000 #{0x00010001, 0x0000002B} mw 0x1f00080 0x01000100 mw 0x1f00084 0x2b000000 #{0x00010002, 0x00000033} mw 0x1f00080 0x02000100 mw 0x1f00084 0x33000000 #{0x00010003, 0x0000003B} mw 0x1f00080 0x03000100 mw 0x1f00084 0x3b000000 #{0x00010004, 0x00000043} mw 0x1f00080 0x04000100 mw 0x1f00084 0x43000000	

Table continues on the next page...

Table 4. Example U-Boot commands that initialize TMU

Example of a U-Boot series of command that initializes TMU	Comments
#{0x00010005, 0x0000004B} mw 0x1f00080 0x05000100 mw 0x1f00084 0x4b000000 #{0x00010006, 0x00000054} mw 0x1f00080 0x06000100 mw 0x1f00084 0x54000000 #{0x00010007, 0x0000005C} mw 0x1f00080 0x07000100 mw 0x1f00084 0x5c000000 #{0x00010008, 0x00000064} mw 0x1f00080 0x08000100 mw 0x1f00084 0x64000000 #{0x00010009, 0x0000006C} mw 0x1f00080 0x09000100 mw 0x1f00084 0x6c000000 #================================ #====TTR2CR, 7 points at 76°C ===== #{0x00020000, 0x00000021} mw 0x1f00080 0x00000200 mw 0x1f00084 0x21000000 #{0x00020001, 0x0000002C} mw 0x1f00080 0x01000200 mw 0x1f00084 0x2c000000 #{0x00020002, 0x00000036} mw 0x1f00080 0x02000200 mw 0x1f00084 0x36000000 #{0x00020003, 0x00000040} mw 0x1f00080 0x03000200 mw 0x1f00084 0x40000000	

Table continues on the next page...

Table 4. Example U-Boot commands that initialize TMU

Example of a U-Boot series of command that initializes TMU	Comments
#{0x00020004, 0x0000004B} mw 0x1f00080 0x04000200 mw 0x1f00084 0x4b000000 #{0x00020005, 0x00000055} mw 0x1f00080 0x05000200 mw 0x1f00084 0x55000000 #{0x00020006, 0x0000005F} mw 0x1f00080 0x06000200 mw 0x1f00084 0x5f000000 #===TTR3CR, 8 points at 98°C====== #{0x00030000, 0x00000013} mw 0x1f00080 0x00000300 mw 0x1f00084 0x13000000 #{0x00030001, 0x0000001D} mw 0x1f00080 0x01000300 mw 0x1f00084 0x1d000000 #{0x00030002, 0x00000028} mw 0x1f00080 0x02000300 mw 0x1f00084 0x28000000 #{0x00030003, 0x00000032} mw 0x1f00080 0x03000300 mw 0x1f00084 0x32000000 #{0x00030004, 0x0000003D} mw 0x1f00080 0x04000300 mw 0x1f00084 0x3d000000 #{0x00030005, 0x00000047} mw 0x1f00080 0x05000300 mw 0x1f00084 0x47000000 #{0x00030006, 0x00000052} mw 0x1f00080 0x06000300 mw 0x1f00084 0x52000000	

Table continues on the next page...

Table 4. Example U-Boot commands that initialize TMU

Example of a U-Boot series of command that initializes TMU	Comments
#{0x00030007, 0x0000005C} mw 0x1f00080 0x07000300 mw 0x1f00084 0x5c000000 #========== #===1 seconds timer monitor===== mw 0x1f00008 0x08000000 #========== #=========Enable TMU and all sites====== mw 0x1f00000 0x00f80080 #========== md 0x1f00100	

4 Using U-Boot and Linux commands to read temperature

Use the following commands to do LS1043ARDB temperature measurement.

Table 5. Commands to read temperature

In U-Boot mode	>sensors
In Linux	root@ls1043ardb:~# cat /sys/class/thermal/thermal_zone0/temp

NOTE

The sensors command in U-Boot does not read the TMU. Instead, it reads the I2C chip that reads the thermal diode temperature which should be close to the TMU reading when in Linux mode. The provided initialization sequence in the previous section allows user to read TMU temperature while being in U-Boot without the need to boot Linux. Thus, you can display the TMU registers with this command example:

```
md 0x1f00100
01f00100: 25000080 25000080 00000000 00000000    ...%...%........
01f00110: 23000080 23000080 00000000 00000000    ...#...#........
01f00120: 24000080 24000080 00000000 00000000    ...$...$........
01f00130: 24000080 24000080 00000000 00000000    ...$...$........
01f00140: 23000080 23000080 00000000 00000000    ...#...#........
```

```
01f00150: 00000000 00000000 00000000 00000000    ................
01f00160: 00000000 00000000 00000000 00000000    ................
01f00170: 00000000 00000000 00000000 00000000    ................
01f00180: 00000000 00000000 00000000 00000000    ................
01f00190: 00000000 00000000 00000000 00000000    ................
01f001a0: 00000000 00000000 00000000 00000000    ................
01f001b0: 00000000 00000000 00000000 00000000    ................
01f001c0: 00000000 00000000 00000000 00000000    ................
01f001d0: 00000000 00000000 00000000 00000000    ................
01f001e0: 00000000 00000000 00000000 00000000    ................
01f001f0: 00000000 00000000 00000000 00000000    ................
```

and then read all TMU sensors readings, the average and the current per memory map below:

Table 6. LS1043A TMU memory map example at TMU base address 0x01F0_0000

Offset	Register	Width	Access	Example Reading
100h	TMU report immediate temperature site register 0 (TRITSR0)	32	RO	0x25000080 Valid reading temp = 25Hex = 37 °C
104h	TMU report average temperature site register 0 (TRATSR0)	32	RO	0x25000080 Valid reading temp = 25Hex = 37 °C
110h	TMU report immediate temperature site register 1 (TRITSR1)	32	RO	0x23000080 Valid reading temp = 23Hex = 35 °C
114h	TMU report average temperature site register 1 (TRATSR1)	32	RO	0x23000080 Valid reading temp = 23Hex = 35 °C
120h	TMU report immediate temperature site register 2 (TRITSR2)	32	RO	0x24000080 Valid reading temp = 24Hex = 36 °C
124h	TMU report average temperature site register 2 (TRATSR2)	32	RO	0x24000080 Valid reading temp = 24Hex = 36 °C
130h	TMU report immediate temperature site register 3 (TRITSR3)	32	RO	0x24000080 Valid reading temp = 24Hex = 36 °C
134h	TMU report average temperature site register 3 (TRATSR3)	32	RO	0x24000080 Valid reading

Table continues on the next page...

Table 6. LS1043A TMU memory map example at TMU base address 0x01F0_0000 (continued)

Offset	Register	Width	Access	Example Reading
				temp = 24Hex = 36 °C
140h	TMU report immediate temperature site register 4 (TRITSR4)	32	RO	0x23000080 Valid reading temp = 23Hex = 35 °C
144h	TMU report average temperature site register 4 (TRATSR4)	32	RO	0x23000080 Valid reading temp = 23Hex = 35 °C

5 Related documentation

Refer to the following documents. Contact your NXP sales representative for access to any documents that are not publicly available on the NXP external website.

- AN4787 - Temperature Measurements Using an On-Die Thermal Diode
- LS1xxx and LS2xxx reference manuals and data sheets

6 Revision history

This table summarizes the revisions to this document.

Table 7. Revision history

Revision	Date	Description
0	27 April 2022	Initial release

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