Temperature Control

Application Note for 64-bit NuMicro® Family

Document Information

Abstract	This document presents an example implementation of MA35D1 chip temperature management.
Apply to	NuMicro® MA35D1 series.

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1 Overview

Modern system on chip (SOC) contains multiple CPU cores, the processor frequency is higher, the grid is dense and leaks more in the same area, so system management at higher temperatures needs to be considered.

When running in a high temperature environment and system running with heavy loading, MA35D1 chip temperature may becomes high. It is important to cool down the chip to prevent from system execution abnormal. Slow down CPU working frequency, system clock, PLL clock, and engine clock can help to cool down chip. Physical countermeasures, such as the use of fans, can help cool the IC more effectively.

This document presents an implementation example of temperature control. This example divides the MA35D1 temperature state into 4 temperature zones. Zone1 is the temperature range in which the chip normally operates, while Zone2 ~ Zone4 are the high temperature range of the chip, and different cooling strategies must be adopted.

MA35D1 is equipped with a thermal sensor, and the Linux thermal driver supports to read the current temperature value from it.

MA35D1 Linux BSP contains the proprietary ma35d1-misctrl driver for supporting chip cooling. This driver provide several ioctl methods to provide PMIC voltage control, CPU clock control, EPLL/VPLL clock control, and SYS-PLL control.

2 Temperature Zones and Control

2.1 Temperature Zones

This example implementation of MA35D1 temperature control divides the chip temperature state into four zones by temperature range, as shown in Figure 2-1.

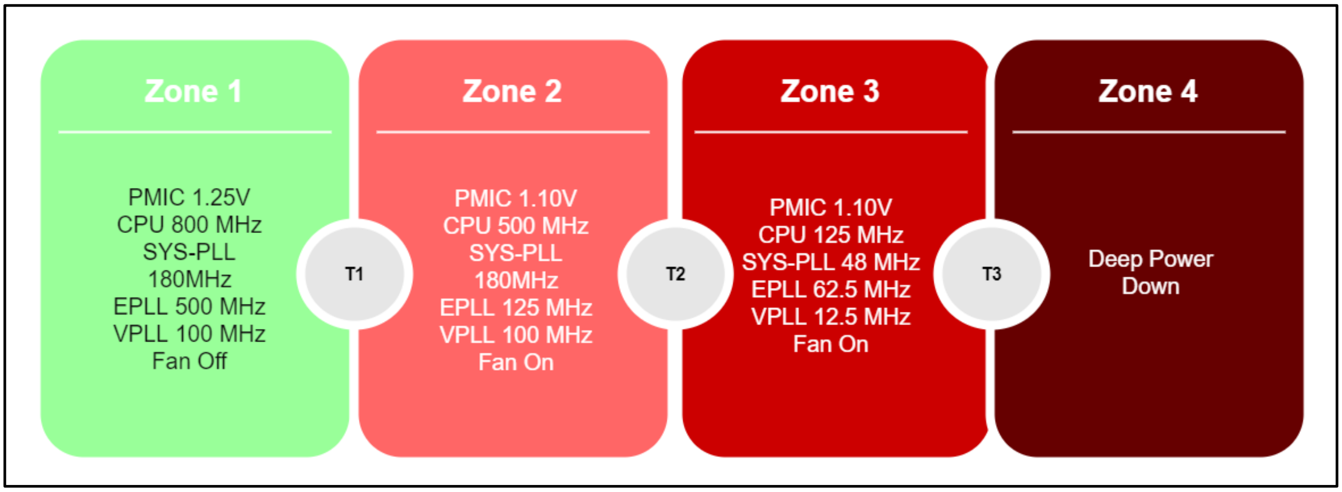

Figure 2-1 Temperature Zones

Zone 1 is the normal run zone. When the temperature rising over T1, the chip enters Zone 2 and this example will slow down CPU clock to 500 MHz, reduce PMIC to 1.10V, make EPLL divided by 2, and turn on the fan if presented. If the temperature keep rising over T2, the chip enters Zone 3 and this example will slow down CPU clock to 125 MHz, slow down SYS-PLL to 48 MHz, make both EPLL and VPLL divided by 8, and keep fan on. If the temperature keep rising over T3, the chip enters Zone 4 and this example will force system enter deep power down state and setup RTC to wakeup system after a period of time.

2.2 Temperature State Transition

The transition between temperature states are determined by the current temperature measured by MA35D1 built-in temperature sensor. This example defines four constant to indicate the transition conditions of temperature zone transition.

```
#define T_Z1_TO_Z2       115  /* Enter Z2 once larger than T_Z1_TO_Z2 */
#define T_Z2_TO_Z3       120  /* Enter Z3 once larger than T_Z2_TO_Z3 */
#define T_Z3_TO_Z4       125  /* Enter Z4 once larger than T_Z3_TO_Z4 */
#define T_DOWN_TO_Z1     105  /* Once enter Z2/Z3/Z4, keep cooling until lower than
                                 T_DOWN_TO_Z1 to back to Zone 1 */
```

In Figure 2-2, T_Z1_TO_Z2, T_Z2_TO_Z3, and T_Z3_TO_Z4 are referred to T1, T2, and T3 respectively. T_DOWN_TO_Z1 is referred to T0, and t is the temperature read from the temperature sensor. Once the chip temperature enters zone 2/3/4, it goes back to zone 1 only when the temperature is cooling down to be lower than T0. Note that T0 is lower than T1 generally, that intends to prevent frequent state transition.

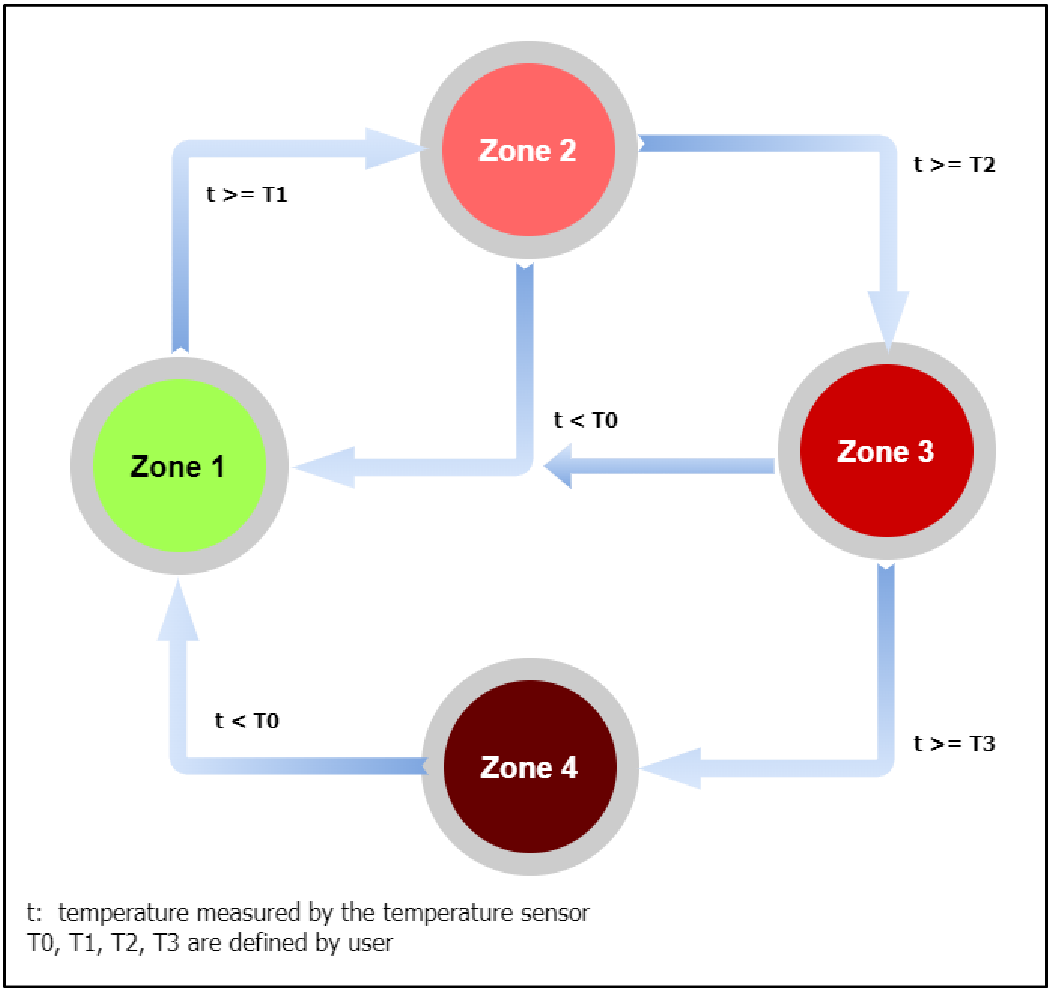

Figure 2-2 Temperature Zone Transition

3 Temperature Management Example

3.1 Required Drivers

This example program requires three drivers, temperature sensor driver, RTC driver, and miscellaneous control driver.

3.1.1 Thermal Sensor Driver

The MA35d1 thermal driver obtains temperature from the thermal sensor registers and transmit the temperature to the subsystem of the Linux kernel.

MA35D1 has only one thermal sensor to measure the processor temperature. So there’s only 1 thermal zone and the sensor is assigned as “<&tsen>”. “polling-delay-passive” is the maximum number of milliseconds to wait between polls when performing passive cooling and “polling-delay” is the maximum number of milliseconds to wait between polls when checking this thermal zone. The “polling-delay” should set with a minimum value of 400. “polling-delay-passive” can set to 0 or other value if preferred

```
tsen: tsen {
    compatible = "nuvoton,ma35d1-tsen";
    #thermal-sensor-cells = <0>;
    nuvoton,ma35d1-sys = <&sys>;
    status = "okay";
};
thermal-zones {
    cpu_thermal: cpu-thermal {
        polling-delay-passive = <0>;
        polling-delay = <400>;
        thermal-sensors = <&tsen>;
    };
};
```

3.1.2 RTC Driver

This example performs the system deep power down when the temperature state raised to zone 4. Before entering power down, this example configures the RTC to wake up system later. Check device tree to make sure RTC driver is enabled.

```
rtc: rtc@40410000 {
    compatible = "nuvoton,ma35d1-rtc";
    reg = <0x0 0x40410000 0x0 0x10000>;
    interrupts = <GIC_SPI 5 IRQ_TYPE_LEVEL_HIGH>;
    clocks = <&clk RTC_GATE>;
```

```
    status = "okay";
};
```

3.1.3 Miscellaneous Control Driver

The miscellaneous control driver provides a set of ioctl commands for configuring PMIC voltage, CPU clock, EPLL, VPLL, and SYS-PLL. Check device tree to make sure miscellaneous control driver is enabled.

```
misctrl {
    compatible    = "nuvoton,ma35d1-misctrl";
    status = "disabled";
};
```

3.2 The Example Code

The temperature control example can be download from github repository: https://github.com/OpenNuvoton/MA35D1_Linux_Applications. It can be found in the examples/temp_ctrl folder.

4 Hardware Setup

4.1 Fan Control Schematic

Figure 4-1 shows the fan control circuit on the NuMaker-BASE-MA35D1B1 V2.1 base board. The GPIO PI4 is a dedicated pin for this fan control function (FAN_EN, = High to turn on the fan, = Low to turn off the fan). For more detail information about the NuMaker-HMI-MA35D1-S1 board, please refer to the NuMaker-HMI-MA35D1-S1 User Manual document on the [Nuvoton website.]

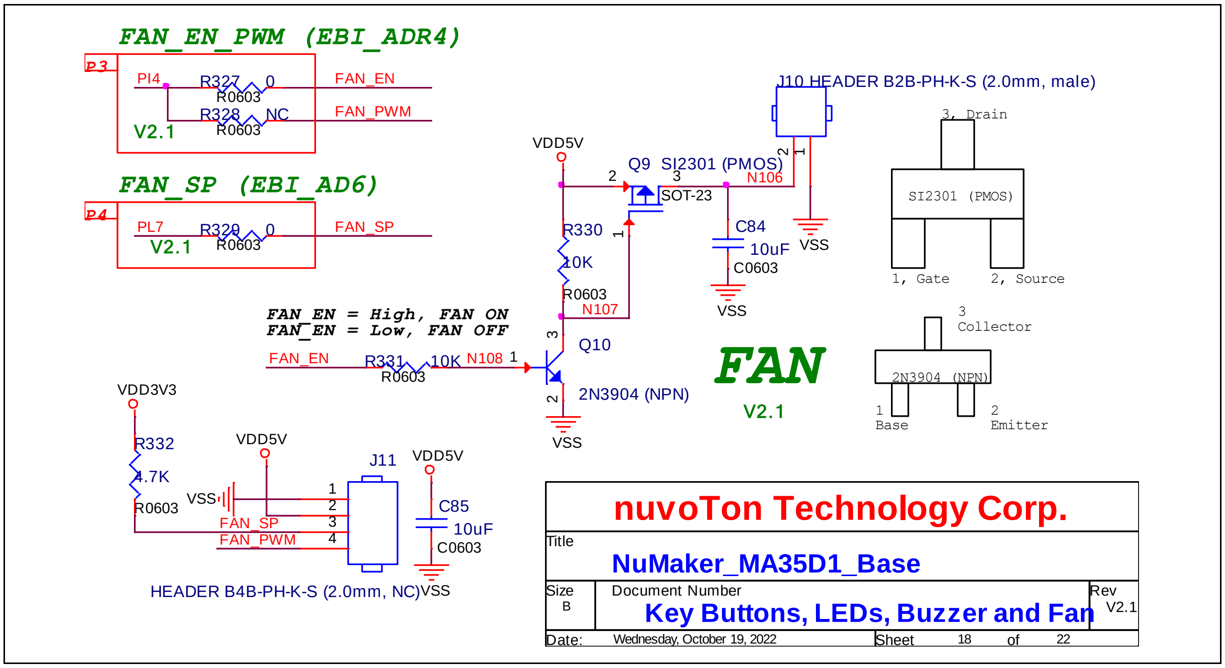

Figure 4-1 Fan Control Schematic

4.2 Fan Component and Setup

Figure 4-2 shows the fan component with its connector. The connector of fan component should be connected to the J10 header on the NuMaker-BASE-MA35D1B1 V2.1 base board. The picture of fan assembled on the NuMaker-BASE-MA35D1B1 V2.1 base board is shown in Figure 4-3 Fan Assembled on NuMaker-BASE-MA35D1B1 V2.1 Base BoardFigure 4-3 Fan .

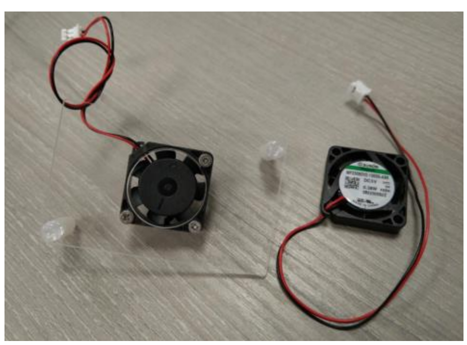

Figure 4-2 Fan Component

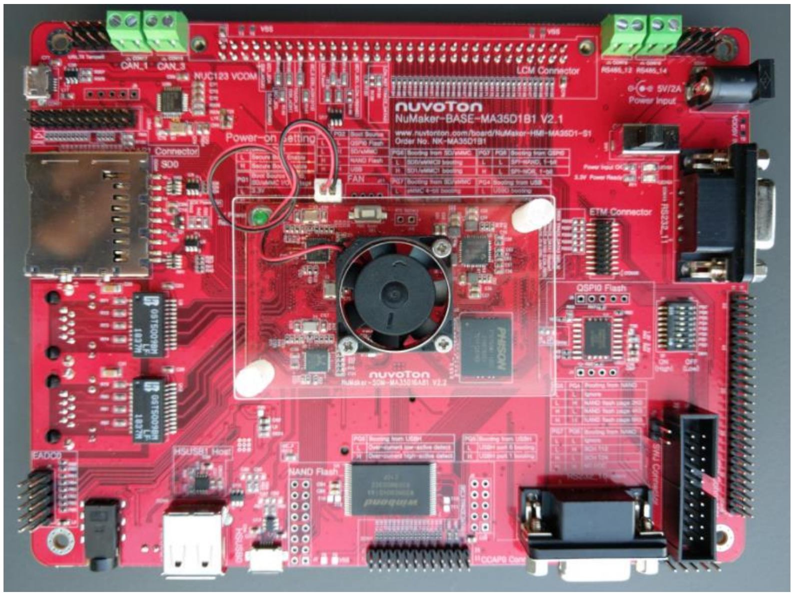

Figure 4-3 Fan Assembled on NuMaker-BASE-MA35D1B1 V2.1 Base Board

5 Junction Temperature and Heat Radiation Consideration

5.1 Thermal Characteristics

The Table 5-1 shows the thermal characteristics of MA35D1 chip at different package type. The absolute junction temperature T_J of MA35D1 chip is 125^OC. The typical values of thermal resistance junction-ambient θ_{JA} are determined according to JESD51 Integrated Circuits Thermal Test Method Environment Conditions; the Printed Circuit Board (PCB) is 4 layers (2S2P) and FR4 material in 1.6mm thickness, the copper thickness is 2-OZ for Microstrip (Top/Bottom) layer and 1-OZ for Stripline (Inner) layer, the PCB size is 3'' x 4.5'' (LQFP-216 package type) or 4'' x 4.5'' (BGA package type).

Symbol	Description	Min	Typ	Max	Unit
T_J [*1]	Junction Temperature (Absolute)	-40	-	125	^OC
T_{ST}	Storage Temperature	-65	-	150	
θ_{JA} [*2]	Thermal Resistance Junction-Ambient LQFP-EP 216-Pin (24x24 mm)	-	17.6	-	^OC/Watt
	Thermal Resistance Junction-Ambient LFBGA 312-Ball (15x15 mm)	-	21.7	-	^OC/Watt
	Thermal Resistance Junction-Ambient TFBGA 364-Ball (14x14 mm)	-	25.1	-	^OC/Watt

Note:

1. The average junction temperature can be calculated by using the following equation:

   $T_J = T_A + (PD \times \theta_{JA})$

   - T_A = ambient temperature (^OC)
   - θ_{JA} = thermal resistance junction-ambient (^OC/Watt)
   - PD = sum of internal and I/O power dissipation

2. Determined according to JESD51 Integrated Circuits Thermal Test Method Environment Conditions,
   - FR4 PCB thickness is 1.6mm
   - Copper thickness is 2-OZ for Microstrip (Top/Bottom) layer
   - Copper thickness is 1-OZ for stripline (Inner) layer
   - LQFP216 follows JESD 51-7, 2S2P PCB is size 3" x 4.5"
   - BGA follows JESD 51-9, 2S2P PCB size is 4" x 4.5"

Table 5-1 Thermal Characteristics

5.2 Recommended Thermal Operation Conditions

To keep the tolerance and guarantee MA35D1 chip can operate normally and safely below the maximum junction temperature T_J, the recommended T_J is 105^OC and the maximum allowable power dissipation are also recommended for different package types and different ambient temperature T_A shown in Table 5-2.

Symbol	Parameter	Conditions	Min	Max	Unit
T_J	Junction Temperature		-	105	^OC

PD	Allowable Power Dissipation	LQFP-EP 216-Pin (24x24 mm) at $T_A = 85^{O}C$	-	1.1	Watt
		LQFP-EP 216-Pin (24x24 mm) at $T_A = 70^{O}C$	-	1.9	Watt
		LFBGA 312-Ball (15x15 mm) at $T_A = 70^{O}C$	-	1.6	Watt
		TFBGA 364-Ball (14x14 mm) at $T_A = 70^{O}C$	-	1.3	Watt
Note:					

Table 5-2 Recommended Thermal Operation Conditions

5.3 Heat Radiation Consideration

5.3.1 PCB Size

The common knowledge, the larger PCB size, the better for heat radiation. If it is possible and allowable, to make the PCB size as large as possible. Table 5-3 shows the θ_{JA} vs. PCB size.

MA35D1	**θ_{JA} (^{O}C/Watt) vs. PCB Size**			**Unit**
Package Type	**30cm^2**	**55cm^2**	**80cm^2**	
LFBGA 312-Ball (15x15 mm)	TBD[*1]	TBD[*1]	TBD[*1]	^{O}C/Watt
TFBGA 364-Ball (14x14 mm)	TBD[*1]	TBD[*1]	TBD[*1]	^{O}C/Watt

Note:

1. PCB Conditions,
   - 8 layers in PCB stack-up
   - FR4 PCB thickness is 1.6mm
   - Copper thickness is 1-OZ for Microstrip (Top/Bottom) layer and copper ratio is 30% in Top/Bottom layers
   - Copper thickness is 1-OZ for stripline (Inner) layer and copper ratio is 90% in Inner layers
   - Thermal vias follow the JEDEC rules
   - No air flow

Table 5-3 θ_{JA} vs. PCB Size

5.3.2 Copper Thickness of PCB Stack-up

The copper thickness of each layer in PCB stack-up is also good for heat radiation and also needed to be considered. It is good making the PCB at least 1-OZ copper thickness in each layer in PCB stack-up.

5.3.2 Other Methods to Reduce the Temperature of Chip

Perhaps, if it is possible and allowable in the outer casing, it is recommended to add the heatsink on the surface of chip or a fan control to reduce the temperature of chip.

6 Conclusion

Users can easily obtain the current system core temperature through the temperature sensor driver and perform cooling operations provided by the miscellaneous driver. It is suggested to customized this example to add more countermeasures when core temperature is getting high, for example, force to close some heavy loading applications, sound warning, shutdown, etc.

Revision History

Date	Revision	Description
2022.11.01	1.00	1. Initially issued.

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