Freescale Semiconductor
Application Note

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Automatic Thermal Monitoring System on HPC II

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1 Introduction

This application note applies to the MPC7447A and MPC7448 processors embedded on an HPC II platform. It describes the implementation of an Automatic Thermal Monitoring System (ATMS), used to automatically control the processor core temperature. When activated, the ATMS cools the processor by two methods: CPU fan control and CPU frequency throttling, known as Dynamic Frequency Switching (DFS). The benefits of implementing an ATMS system are threefold: it reduces power consumption, reduces noise, and provides a fail-safe mechanism that powers off the system in the event of extreme operating temperatures.

The following section descriptions provide an overview of this document.

Section 2, "Functional Overview," provides a top-level view of the ATMS and how the on-board hardware interfaces and communicates.

Section 3, "Functional Philosophy," describes the major functional components of the ATMS.

Contents

Section 4, "DINK32 on HPC II Board," gives some kernel specific instructions for those operating under DINK32 on a HPC II development board.

Section 5, "Conclusion," gives closing remarks.

Section 6, "References," provides a list of references.

Section 7, "Revision History," gives the revision history for this document.

Appendix A, "Ideality Factor Determination," details the methodology used to determine the ideality factor of the CPU thermal diode.

Appendix B, "Pseudocode," contains verbose pseudocode for all of the functions that comprise the ATMS.

2 Functional Overview

Figure 1 shows a simplified block diagram of the ATMS. The ATMS is possible by way of the thermal diode which resides on the processor die. A temperature reading can be determined by measuring the change in the base-emitter voltage (V_{BE}) of the diode when operated at different currents. The resulting ΔV_{BE} measurements can then be digitized and a die junction temperature produced. In this implementation a thermal monitor chip ADT7461 was used to read the diode temperature. Standard A/D can be used whereby exploiting the negative temperature coefficient of the diode can be used to measure V_{BE}. However, this method would require a non-trivial amount of calibration due to a number of factors. For example, parasitic series resistance with the remote diode appears as a DC offset. This introduces an error factor in the temperature reading seen as a number of °C per ohm of parasitic resistance (°C/Ω). The absolute value of V_{BE}, which varies from device to device, also appears as a constant temperature offset. For these reasons, specialized devices which can automatically compensate for many or all of these factors are typically used. Otherwise these errors must be compensated for in software.

The main function of the Thermal Sensor within the ATMS is to interface with the thermal diode to produce a temperature reading. The ADT7461 is a dual-channel digital thermometer and under/over temperature alarm. It provides the extra benefit of two temperature limit flags, namely THERM and ALERT/THERM2. These flags are asserted when either a THERM limit or a Temperature High/Low limit is exceeded; both of these limits are user programmable. The THERM flag translates to THERM_ALARM in the FPGA (Actel ProASICPLUS) which in turn asserts the system interrupt INT[1] to the bridge chip (Tsi108). ALERT/THERM2 translates to OVER_ALARM in the FPGA which in turn produces the system interrupt INT[0]. The bridge chip is responsible for then asserting an interrupt (INT) to the CPU. These two interrupts provide the automatic capability of the ATMS, enabling system interrupts and the ATMS to generate interrupts at key temperature thresholds and perform the action necessary to cool the system, all without any user interaction. The reads and writes to the thermal sensor are done through an I^2C bus or similar protocol (that is, SMBus). Note that while two interrupt lines were available in this specific implementation, it is possible to implement the ATMS with only one interrupt line. In the one interrupt line case, software would need to determine what caused the interrupt (possibly by reading registers in the FPGA), and after the cause was determined would then need to take the appropriate action.

NOTE

Freescale makes no recommendations about the components used in this design. Similar components from other vendors provide similar results. The remainder of this application note details the setup used in Freescale's DSD Applications Lab.

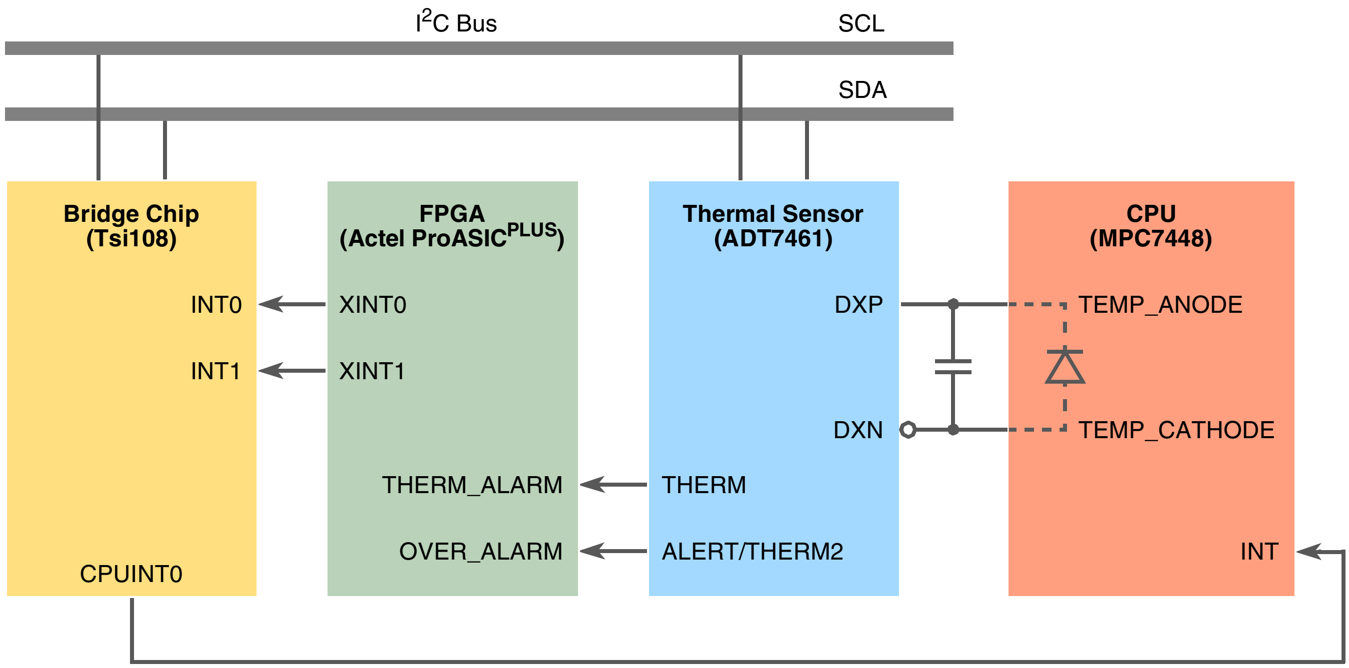


Figure 1. Functional Block Diagram of ATMS

3 Functional Philosophy

The three main operations covered in this application note are as follows:

1. Calibration of the ATMS using environment variables
2. Command line options of the ATMS
3. System interrupts

Figure 2 shows the structure of the code that controls the ATMS, broken into the three main components of the system. The italicized functions are those that pertain specifically to the ATMS. The file main.c contains the **main()** loop for the kernel. In this implementation the kernel is Freescale's Dynamic Interactive Nano Kernel for 32-bit processors (DINK32), which is publicly available under license from Freescale. During boot up DINK32 initializes the environment which makes calls to the ATMS specific functions **adt7461_init()** and **fan_init()**, described in detail in Section 3.1, "Calibration on Startup." The file gme.c contains a number of device operations and command line processing for DINK32, and specifically to the ATMS, contains the code to handle the command line options available to interface and calibrate the ATMS. These functions are described more thoroughly in Section 4.2, "Command Line Interface." The file mpic1.c is the interrupt handler for DINK32. It is responsible for initializing the ATMS when system interrupts are enabled as well as for calling the proper interrupt handler for the THERM and ALERT/THERM2 flags when they are asserted. The ATMS specific functions **ISR_INT0()**, **ISR_INT1()**, and **adt7461_interrupt_init()** provide the automatic interrupt functionality and are described in more detail in Section 3.2, “System Interrupts.”

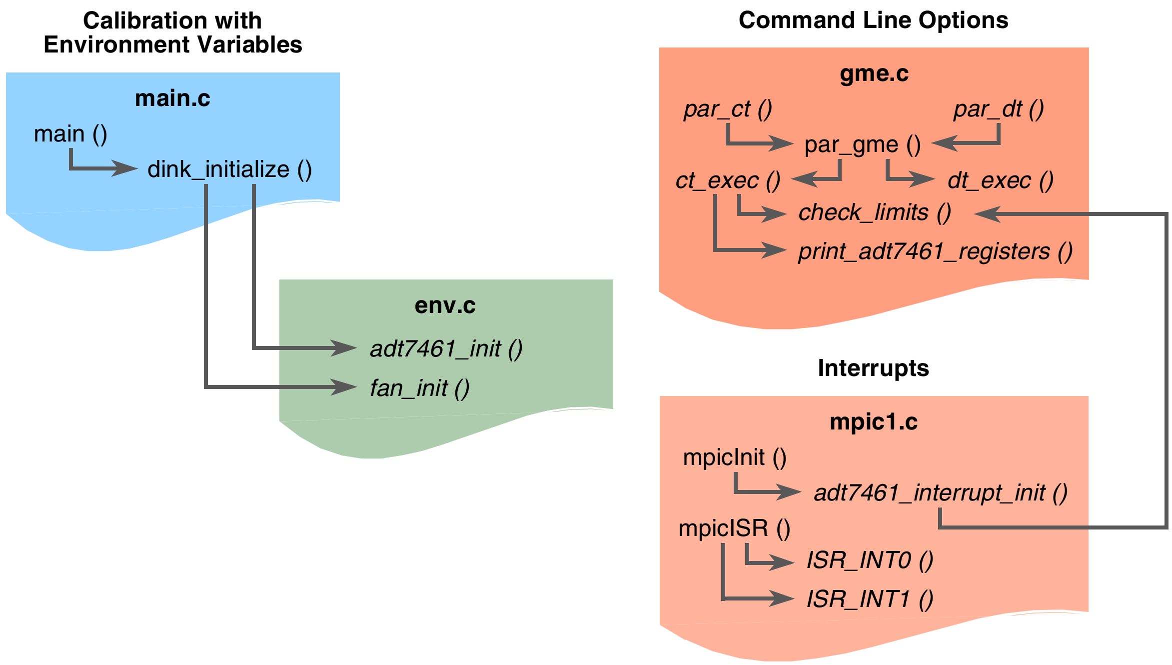


Figure 2. Function Hierarchy of ATMS Software

3.1 Calibration on Startup

On system boot up the ATMS is calibrated by writing to the Thermal Sensor registers. The function **adt7461_init()** handles making the initial writes on the I^2C bus to calibrate the Thermal Sensor. Table 1 gives the register values for this specific implementation of the ATMS. Again, these values are user and system specific and with different preferences, or devices, will change accordingly. See *ADT7461 ±1°C Temperature Monitor with Series Resistance Cancellation Specification*, for further details about these registers.

Table 1. Initial Register Writes to Thermal Sensor (ADT7461) on Boot Up

Register Name	Write Address (Hex)	Power-On Default	Written Value at Boot Up (Hex)	Reason
Configuration	09	0x00	if (Disable7461 == 0) 0xA0 if (Disable7461 == 1) 0xE0	Disable7461 is a global variable that is assigned based on the current ATMS status. It is 0 if the ATMS is enabled and 1 if the ATMS is disabled.
Conversion Rate	0A	0x08	0x07 (8 c/s)	At 8 Conversions/Second the ADT7461 does its own internal averaging. At > 8c/s no averaging is done.
Local Temp High Limit	0B	0x55	if (CPU == MPC7447A) 0x34 (52°C) if (CPU == MPC7448) 0x2C (44°C)	Same as CPU core temperature limit.

Table 1. Initial Register Writes to Thermal Sensor (ADT7461) on Boot Up (continued)

Register Name	Write Address (Hex)	Power-On Default	Written Value at Boot Up (Hex)	Reason
Local Temp Low Limit	0C	0x00	0x00 (0°C)	Unchanged
Ext Temp High Limit High Byte	0D	0x55	if (CPU == MPC7447A) 0x34 (52°C) if (CPU == MPC7448) 0x2C (44°C)	During applications lab testing with a MPC7447A, 52°C (0x34) was the peak temperature the CPU reached when powered on without strenuous code execution. For the MPC7448 this value was 44°C (0x2C). **Note:** These thermal limits are system and processor specific.
Ext Temp Low Limit High Byte	0E	0x00	0x00	Unchanged
Ext Temp Offset High Byte	11	0x00	if (CPU == MPC7447A AND TOFFSET == NULL) 0x00 if (CPU == MPC7448 AND TOFFSET == NULL) 0xFC (-4°C) if (TOFFSET != NULL) TOFFSET	TOFFSET is an environment variable that is checked on bootup. If TOFFSET is defined then its value is used as the DC offset value applied to the Thermal Sensor. If TOFFSET is not defined then a default value is written based on CPU type. The MPC7447A was not tested for this in the DSD applications lab so this specific implementation uses the ADT7461 default of zero. However, it is recommended that the worst case ideality factor, given in the hardware specification, be used to determine the default DC offset.
Ext Temp Offset Low Byte	12	0x00	0x00	0.25° decimal precision is not used in this implementation.
Ext Temp High Limit Low Byte	13	0x00	0x00	Unchanged
Ext Temp Low Limit Low Byte	14	0x00	0x00	Unchanged
External THERM Limit	19	0x55	0x55 (85°C)	Unchanged
Local THERM Limit [1]	20	0x55	0x55 (85°C)	Unchanged
THERM Hysteresis	21	0x0A	if (CPU == MPC7447A) 0x04 (4) if (CPU == MPC7448) 0x05 (5)	These values were derived from DSD applications lab testing. Table 2 gives the results of this testing. The desired value is one that reduces power consumption, overall noise, and still properly controls the temperature.
Consecutive ALERT	22	0x01	0x00	Since the critical overheat temperature is set to 100°C by default, it is desirable to have this interrupt trigger immediately since it is unlikely to occur twice before the CPU reaches its maximum temperature rating.

[1] "Local" temperature limits refer to the internal temperature monitor of the ADT7461, "external" limits refer to temperatures read from the CPU thermal diode.

Note: the ATMS monitors both local and external limits. Therefore if the ambient temperature around the ADT7461 reaches any of the temperature thresholds the corresponding interrupts will be triggered as if the temperature was read from the CPU thermal diode.

Table 2. Number of Interrupt Calls Versus Hysteresis Values

Hysteresis Effect on MPC7447A with External and Local Temperature Thresholds set to 0x34 (52°C)				
DC Offset: 0°C				
Hysteresis Value	Length of Test (min)	# INT Calls	Minutes / Call	Calls / Min
0x00	4	236	0.017	59.000
0x01	14	18	0.778	1.286
0x02	20	11	1.818	0.550
0x03	100	47	2.128	0.470
0x04	1020	211	4.834	0.207
0x05	120	1	120.000	0.008
Hysteresis Effect on MPC7448 with External and Local Temperature Thresholds set to 0x2C (44°C)				
DC Offset: –4°C				
Hysteresis Value	Length of Test (min)	# INT Calls	Minutes / Call	Calls / Min
0x00	1	59	0.017	59.000
0x01	17	16	1.063	0.941
0x02	28	15	1.867	0.536
0x03	53	19	2.789	0.358
0x04	92	20	4.600	0.217
0x05	83	8	10.375	0.096

Four environment variables directly affect the ATMS setup: TOFFSET, FANPWM, TDISABLE, and TSHUTDOWN.

TOFFSET allows for individual systems to be calibrated after a specific ideality factor is found for that system. This environment variable sets the DC offset of the Thermal Sensor, which is then automatically applied on every temperature read. If this variable is not set then a default DC offset is assigned depending on processor type. If the ideality factor (n_f) of a device is defined in the hardware specification then use that value to determine the default DC offset. Use Equation 1 in Appendix A, "Ideality Factor Determination," to directly find this DC offset given n_f. However, if an n_f value is not known or a more specific n_f value is required, Appendix A outlines a methodology to determine the n_f and DC offset for a specific device. Testing done on a MPC7448 processor in the DSD applications lab found an overall average temperature reading of 4.32° above expected, corresponding to a value of –4°C as the default DC offset for this implementation. This value of –4°C is applied as a default when TOFFSET is not defined for a MPC7448.

FANPWM, if defined, is used as the fan speed when the ATMS is enabled and no thermal thresholds have been exceeded. If FANPWM is not defined, then a default value of 50% is used for the fan speed when the ATMS is idle and no thresholds have been reached. FANPWM also provides the user the ability to control the CPU fan speed regardless of the ATMS status. Whether the ATMS is enabled or disabled, FANPWM can be defined to set the fan speed on boot up. Note that when the ATMS is enabled, the fan speed is set to 100% when the first thermal threshold is reached (THERM2).

TDISABLE disables/enables the ATMS. If this environment variable is set to “1” then the ATMS is disabled. When disabled the Thermal Sensor is put in standby mode and no longer makes temperature conversions. System interrupts can also be enabled as these will be ignored by the ATMS when it is disabled. When the ATMS is disabled the CPU fan speed reverts back to the FANPWM environment variable. If this environment variable is not defined the fan is set to 100%.

TSHUTDOWN sets the critical temperature shutdown limit of the ATMS on boot up. This environment variable is part of the fail-safe feature of the ATMS. It guarantees that at a predefined temperature the system will shut down. If TSHUTDOWN is not defined then a default value of 100°C is used as the critical temperature limit.

The function **adt7461_init()** calibrates the ATMS and the function **fan_init()** initializes the fan speed settings using FANPWM. Appendix B, “Pseudocode,” contains commented pseudocode for both of these functions.

3.2 System Interrupts

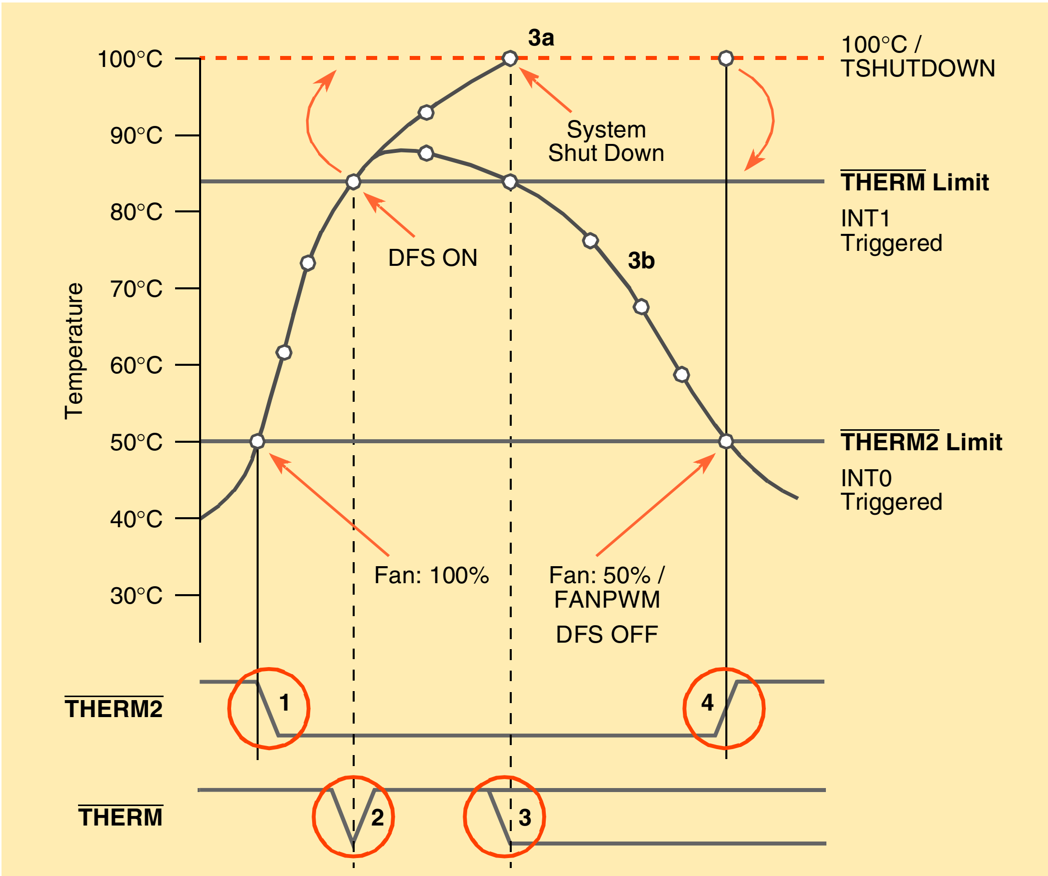
Interrupts provide the ‘automatic’ capability of the ATMS. As mentioned in Section 2, “Functional Overview,” threshold flags sent from the Thermal Sensor are translated to system interrupts, namely INT[0] and INT[1]. The operation of these interrupts and the thermal thresholds that trigger them are shown in Figure 3. Following Figure 3 is a description of what occurs at each edge trigger. Figure 4 is a flowchart showing how the interrupts operate. The parenthesized numbers in the flowchart correspond to the numbered trigger points in Figure 3.

During the design process it was decided that DFS mode will be enabled at the first THERM threshold, but will not be disabled when the temperature drops below this theshold. Instead, DFS mode is kept on until the temperature drops passed the THERM2 trigger limit. Also, during the first INT[1] interrupt call (see point 2 in Figure 3) the THERM limits inside of the Thermal Sensor are changed to the environment variable TSHUTDOWN, if this variable is defined. If TSHUTDOWN is not defined then the THERM limits are changed to a default of 0x64 (100°C). This ensures that if the temperature continues to increase to the critical temperature limit the INT[1] interrupt will still be triggered on a falling edge and a system shut down can occur, providing the fail-safe functionality of the ATMS. Note that this system shut down temperature can be other than 100°C by simply defining the TSHUTDOWN environment variable.

Note that in the HPC II design example, temperatures and THERM limits lower than 0°C were not considered. See the ADT7461 data sheet for a more detailed description of how the temperature limit interrupts work and how they could be used in other implementations.

The interrupt vectors 0 and 1 are initialized in the function **adt7461_interrupt_init()** when the system interrupts are enabled. If the ATMS is disabled, by way of the “ct –d” command or from the TDISABLE environment variable, then the ATMS interrupts will still be initialized but will not be active. After initialization the interrupt service routines responsible for handling the THERM and THERM2 triggers are

ISR_INT1() and **ISR_INT0()** respectively. Pseudocode for these functions can be found in Appendix B, "Pseudocode."



1. When the THERM2 limit is exceeded, the THERM2 signal asserts low. INT0 is triggered and the fan is set to 100%.
2. If the temperature continues to increase and exceeds the THERM limit, the THERM output asserts low. INT1 is triggered and DFS mode is enabled. The THERM limits are overwritten with the critical temperature limit (100°C or TSHUTDOWN if defined).
3. **a.** If the temperature continues to increase and exceeds the second THERM limit (critical temperature limit), the THERM output asserts low. INT1 is called a second time and the system shuts down.
   b. If the temperature does not reach the critical temperature limit, then no action is taken.
4. As the system cools down, and the temperature falls below the THERM2 limit minus hysteresis (in this case it is set to zero), the THERM2 signal resets (goes high). INT0 is called, the fan is set to FANPWM if defined (else 50%), and DFS mode is disabled. The THERM limits are also reset to their previous values (default 0x55).

Figure 3. Operation of the THERM and THERM2 Interrupts

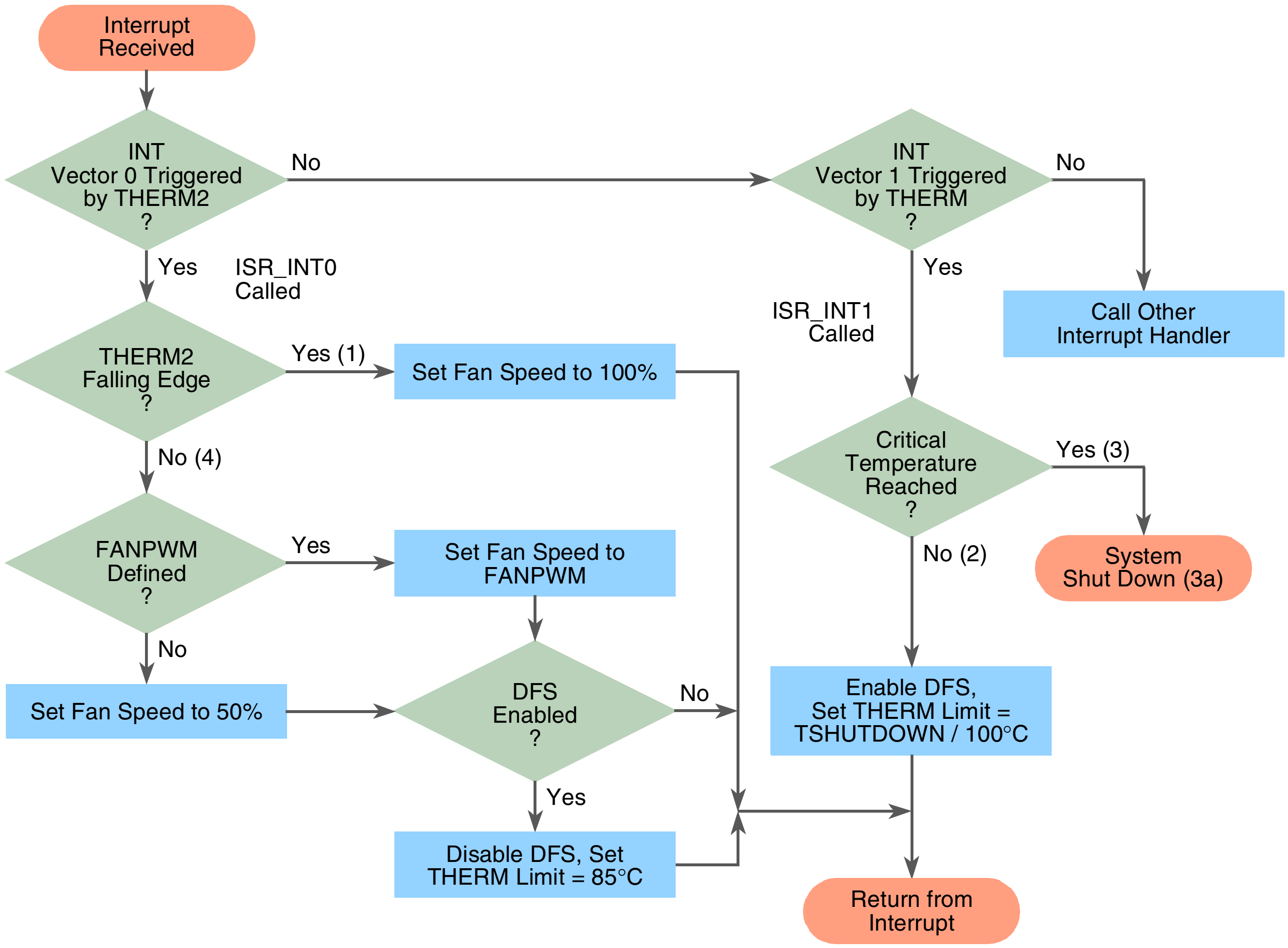


Figure 4. Interrupt Handler Flowchart

4 DINK32 on HPC II Board

When operating under the DINK32 kernel on a HPC II development board the following sections can be used for debug and test purposes. At the DINK32 command prompt, typing “env ?”, “ct ?”, or “dt ?” displays a help screen for the environment variables command, the configure temperature command, or the display temperature command respectively.

Table 3 outlines the references that were used during development of the ATMS. These are specific to the MPC744X line of processors and the HPC II development board, but will provide a greater understanding of how the ATMS was developed.

Table 3. References Used in ATMS Development

Reference	Used During
[1]	...all stages of the ATMS development.
[4]	...development of the interrupt handlers and when modifying the HID1 register. Specifically see section 2.2.5.2.
[5]	...development of the interrupt handlers. Specifically for information on TICK registers that controlled fan speed, power off ability, and interrupt initialization. See section 6.
[6]	...development of interrupt handlers and when modifying the HID1 register. Provided information about PLL bits contained within the HID1 register. See section 9.1.1.
[7]	...development of interrupt handlers and when modifying the HID1 register. Provided information about PLL bits contained within the HID1 register. See section 9.1.1.
[8]	...all stages of the ATMS development.

4.1 Environment

The following instructions outline how to use the environment variables within the DINK32 kernel.

Instructions for using TOFFSET environment variable to set a DC offset on boot up:

1. If there is not a valid environment, type “env –c” to initialize environment, otherwise skip this step.
2. Type “env Verbose=1” to turn verbose mode on.
3. Type “env TOFFSET=*nnn*” where *nnn* is a valid whole number. Type “env ?” for help with TOFFSET.
4. Reset the board.
5. Verify that on ADT7461 initialization the TOFFSET environment variable was found and no FAILURE messages appear by reading the verbose boot messages.
6. Type “ct” to print out the ADT7461 registers. Verify that the correct offset value was written into the Offset register.

Instructions for using TDISABLE environment variable to disable the ATMS:

1. If there is not a valid environment, type “env –c” to initialize environment, otherwise skip this step.
2. Type “env Verbose=1” to turn verbose mode on.
3. Type “env TDISABLE=1” to disable the ATMS.
4. Reset the board.

5. Either apply direct heat or manually modify the ADT7461 registers until a thermal limit is surpassed. Use the “dt” and “ct” commands to monitor the temperature and status register read from ADT7461.
6. Verify that no action is taken even when a thermal limit is surpassed.

Instructions for using FANPWM environment variable to control fan speed:

1. If there is not a valid environment, type “enc –c” to initialize environment, otherwise skip this step.
2. Type “env Verbose=1” to turn verbose mode on.
3. Type “env FANPWM=0x*nnnn*” where *nnnn* is a valid hex value. Type “env ?” for help with FANPWM.
4. Reset the board.
5. Verify that on ADT7461 initialization the FANPWM environment variable was found, the fan speed was set to FANPWM, and no FAILURE messages appear by reading the verbose boot messages. The fan speed should change and any large differences in fan speed should be audible.

Instructions for using TSHUTDOWN environment variable to shut down system:

NOTE

USE WITH CAUTION: A heat gun can melt solder or plastic parts, and a processor with no heat sink quickly overheats!

1. If there is not a valid environment, type “enc –c” to initialize environment, otherwise skip this step.
2. Type “env Verbose=1” to turn verbose mode on.
3. Type “env TSHUTDOWN=*nnn*” where *nnn* is a valid decimal value between 0 and +255. Type “env ?” for help with TSHUTDOWN.
4. Reset the board.
5. Type “dev mpic init” to initialize system interrupts.
6. Use a heat gun or some other means to physically heat the processor. The heat sink can also be removed, however, the processor will reach over 100°C very quickly. Ensure that the system is set up properly and use caution.

   The “dt” command can be used to monitor the real-time temperature.
7. Verify that the board powers off when TSHUTDOWN is reached.

4.2 Command Line Interface

The DINK32 implementation provides two command line options that allow the user to interface with the ATMS. These commands are display temperature (dt) and configure temperature (ct). The “dt” command simply reads the local and external temperature values from the thermal sensor and prints these readings in Celsius and hexadecimal. The “ct” command is the heart of the ATMS and provides robust user capabilities. This command is used for the majority of operations when working with the ATMS. Table 4 gives a description of the syntax and flags used with the “ct” command. Note: If the -a, -d, or -e flags are used they should be used separately from all other flags. Otherwise any number of flags in any order can be used with the “ct” command. Keep in mind that the “dt” and “ct” commands are ADT7461 and DINK32 specific. The functions that handle the processing of the “dt” and “ct” commands are **dt_exec()** and **ct_exec()** respectively. The pseudocode for these functions are in Appendix B, “Pseudocode.”

Table 4. Configure Temperature Command Description

<table>
<tr><td colspan="2">Syntax: ct [-ade] [[-o therm] [-t therm] [-s hyst] [-x xlim] [-l loclim] [-c rate] [-r alert] [-g config]]</td></tr>
<tr><td colspan="2">Description: This command allows the ADT7461 temperature monitor to be fully configured from the command line.

It can also disable/enable the device which in turn disables/enables the entire thermal monitoring system.

Typing only "ct" displays the current register settings, which also display after every “ct” command.

NOTE
The flags -a, -d, and -e can only be used separately from all other flags/options and must be the first flags in the command line!

That is, ct -a (CORRECT)
ct -d (CORRECT)
ct -e (CORRECT)
ct -a -d [or any other flag] (WRONG)</td></tr>
<tr><th>Options:</th><th>Description</th></tr>
<tr><td>-a</td><td>Auto configure Thermal Sensor to power-on default settings.</td></tr>
<tr><td>-d</td><td>Disable the Thermal Sensor and put in standby mode.</td></tr>
<tr><td>-e</td><td>Enable the Thermal Sensor.</td></tr>
<tr><td>-o therm</td><td>Set the Local THERM Limit.</td></tr>
<tr><td>-t therm</td><td>Set the External THERM Limit.</td></tr>
<tr><td>-s hyst</td><td>Set the THERM Hysteresis value.</td></tr>
<tr><td>-x xlim</td><td>Set the External Temperature High Limit.</td></tr>
<tr><td>-l loclim</td><td>Set the Local Temperature High Limit.</td></tr>
<tr><td>-c rate</td><td>Set the Conversion Rate of the Thermal Sensor.</td></tr>
<tr><td>-r alert</td><td>Set the Consecutive ALERT count of the Thermal Sensor.</td></tr>
<tr><td>-g config</td><td>Modify Configuration Register bits in the Thermal Sensor.</td></tr>
<tr><td>therm</td><td>THERM limit value given in hex from 0x00-0xFF.
Default (0x55)(85degC)</td></tr>
<tr><td>hyst</td><td>THERM Hysteresis value given in hex from 0x00-0xFF.
Default (0x0A)(10degC)</td></tr>
<tr><td>xlim</td><td>External Temperature High Limit value given in hex
from 0x00-0xFF. Default (0x55)(85degC)</td></tr>
<tr><td>loclim</td><td>Local Temperature High Limit value given in hex
from 0x00-0xFF. Default (0x55)(85degC)</td></tr>
</table>

Table 4. Configure Temperature Command Description (continued)

Options:	Description
rate	Conversion rate value given in hex. Default (0x08)(16c/s) c/s stands for conversions per second 0x00 -> 0.0625 c/s 0x06 -> 4.0 c/s 0x01 -> 0.125 c/s 0x07 -> 8.0 c/s 0x02 -> 0.25 c/s 0x08 -> 16.0 c/s 0x03 -> 0.5 c/s 0x09 -> 32.0 c/s 0x04 -> 1.0 c/s 0x0A -> 64.0 c/s 0x05 -> 2.0 c/s
alert	Determines how many out-of-limit measurements must occur before an ALERT is generated. 0x00 -> 1 0x03 -> 3 0x01 -> 2 0x07 -> 4
config	8-bit hex value from 0x00-0xFF. Default (0x00) See ADT7461 data sheet for an in depth description of these bits. Bit Name Function 7 MASK1 0=ALERT Enabled, 1=ALERT Masked 6 RUN/STOP 0=Run, 1=Standby 5 ALERT/THERM2 0=ALERT, 1=THERM2 4/3 Reserved 2 Temp Range 0=(0-127)degC, 1=Extended Range 1/0 Reserved

Instructions for starting the ATMS with visual output from DINK32:

1. After the system has been rebooted the ATMS is by default enabled.
2. If there is not a valid environment, type “env –c” to initialize environment, otherwise skip this step.
3. Type “env Verbose=1” to turn verbose mode on.
4. Type “dev mpic init” to initialize system interrupts.
5. The ATMS is now fully functioning with visual feedback.

Instructions for starting the ATMS without visual output from DINK32:

1. After the system has been rebooted the ATMS is by default enabled.
2. Type “dev mpic init” to initialize system interrupts.
3. The ATMS is now fully functioning.

Instructions for using the Display Temperature (dt) command:

1. The “dt” command can be used at any time by simply typing “dt”.

To manually trigger an interrupt:

1. Ensure that the ATMS is enabled and system interrupts are enabled.
2. Type “dt” to display the current temperature reading.

3. Use the "ct" command to modify one of the Temperature Limit or THERM Limit registers to a value that is less than the current temperature displayed when using "dt". This causes the corresponding interrupt to trigger.

   Example: "dt" displays an external temperature of 48.00°C (0x30)
   type "ct –x 0x20" to drop the External Temperature High Limit to 32°C,
   a value below the current temperature reading.
   This immediately triggers the INT[0] interrupt.

Instructions to test whether the ATMS is properly functioning:

1. Reset the board.
2. If there is not a valid environment, type "env –c" to initialize environment, otherwise skip this step.
3. Type "env Verbose=1" to turn verbose mode on.
4. Type "ct –d" to disable the ATMS. Verify the ADT7461 was disabled by analyzing the Configuration register, which is printed out with the other ADT7461 registers on every "ct" command.
5. Type "dev mpic init" to initialize system interrupts.
6. Verify that the interrupts do not trigger and the fan speed is at 100% power.
7. Type "ct –x 0x10" to change the External Temperature High Limit register to 0x10. This causes the THERM2 flag to go low, however, no interrupts should be triggered.
8. Type "ct –e" to enable the ATMS.
9. Verify that the ATMS was enabled and that a thermal threshold had been exceeded. The fan should be at 100% power.
10. Type "ct –t 0x10" to change the External THERM Limit register to 0x10. This causes the THERM flag to go low and should trigger the INT[1] interrupt.
11. Verify that the fan is still at 100% and that DFS mode has been enabled by analyzing HID1 register output. If verbose mode is enabled, then the HID1 register value prints to the screen. See above instructions for how to enable verbose mode.
12. Verify that the External and Local THERM thresholds of the ADT7461 have both been changed to TSHUTDOWN (if defined), else 0x64 (100°C) if TSHUTDOWN is not defined.
13. Type "ct –x 0x60" to change the External Temperature High Limit register to 0x60. If the current temperature is above 0x60 use whatever value is greater than the current temperature reading.
14. Verify that the INT[0] interrupt was triggered. The fan should be set to FANPWM (if defined), otherwise it should be set to 50% power. DFS mode should be disabled. THERM limits should be set back to 0x55 (85°C).
15. Type "ct –d" to disable the ATMS.
16. Verify that the ATMS was disabled by analyzing the Configuration register in the ADT7461 and that the fan is at 100% power.

Instructions to verify that the power off fail-safe is working:

NOTE

USE WITH CAUTION: A heat gun can melt solder or plastic parts, and a processor with no heat sink quickly overheats!

1. Reset the board.
2. Type “dev mpic init” to enable system interrupts.
3. Use a heat gun or some other means to physically heat the processor. The heat sink can also be removed, however, the processor will reach over 100°C very quickly. Ensure that the system is set up properly and use caution.

   The “dt” command can be used to monitor the real-time temperature.
4. Verify that the board powers off at either TSHUTDOWN if it is defined, or 100°C if TSHUTDOWN is not defined.

5 Conclusion

The presence of a substrate thermal diode simplifies the implementation of the ATMS. If a thermal diode is not present on the processor die, it is possible to buy an external transistor (or diode) to place near the processor. This diode can then be interfaced with, in similar means to the substrate diode, to obtain a temperature reading. Freescale’s latest PowerPC processors avoid this extra effort and hardware by providing an on-chip thermal diode that is ready to easily interface with. By providing a third party thermal sensor and software to control the ATMS, it becomes simple to implement a full thermal solution into a system.

6 References

1. Analog Devices. *ADT7461 ±1°C Temperature Monitor with Series Resistance Cancellation Specification*, Rev. 0, 2003.
2. Actel. *ProASICPLUS Flash Family FPGAs Datasheet*, Rev 3.5, 04/2004.
3. Tundra. *Tsi108™: Host Bridge for PowerPC® User Manual*. http://www.tundra.com
4. Freescale Semiconductor, Inc., MPC7450UM, *MPC7450 RISC Microprocessor Family Reference Manual*, Rev.5, 1/2005.
5. Freescale Semiconductor, Inc., HPCIIUG, *HPC II – A High-Performance, Low-Profile Server System*, Rev. 1.1, 7/2005.
6. Freescale Semiconductor, Inc., MPC7448EC, *MPC7448 RISC Microprocessor Hardware Specifications*, Rev. 0, 9/2005.
7. Freescale Semiconductor, Inc., MPC7447AEC, *MPC7447A RISC Microprocessor Hardware Specifications*, Rev. 4, 9/2005.
8. Freescale Semiconductor, Inc., DINKRM, *DINK32 Reference Manual*, Rev 13.2, 8/2005.

7 Revision History

Table 5 provides a revision history for this application note.

Table 5. Document Revision History.

Revision	Date	Substantive Change(s)
0	11/2005	Initial Release

Appendix A Ideality Factor Determination

The ADT7461 is trimmed for an ideality factor (n_f) of 1.008. Likewise, other thermal sensors will assume a certain n_f value. If a transistor is being used whose n_f does not equal 1.008, or the assumed n_f value, then the Thermal Sensor must be calibrated by finding the correct n_f . For the ADT7461, equation (1) is given to determine the error introduced at a temperature *T*. Use this equation to determine the ideality factor by taking thermal measurements to determine *T* and ΔT.

Testing to determine the ideality factor of the MPC7448 thermal diode was done using a Marlow SE5010 Temperature Controller. Four different processors were tested and an average was taken. Note that the ideality factor found in testing will potentially differ from those found in hardware specifications. This is only meant as a way of determining the ideality factor if one is not available, not known, or if a more precise value is desired, since the hardware specifications give a range, and not a single value for n_f. Below are steps to determine the ideality factor of a single device as well as example results obtained in the DSD applications lab for the MPC7448 processor embedded on a HPC II development board.

NOTE

During lab testing the diode always read above the expected value. If it is critical that a system never reach above a specific temperature, then setting the DC offset to 0°C by way of TOFFSET is recommended. This will operate on the 'safe side' since the ATMS errors on the positive side of temperature readings.

Steps for determining ideality factor:

1. Take data points ranging from the minimum processor operating temperature to the maximum. In this example the range was from 5°C—105°. Compare these ideal values with actual values read from the diode using a Thermal Sensor. See Table 6 for an example.
2. Take the difference of the actual vs. expected temperature readings and call this ΔT. See Table 6 for an example.
3. Equation (2) below can then be used to find the ideality factor. ΔT is the difference and *T* is the expected (golden) value. See Table 7 for an example of these results.

$$\Delta T = ((n_f - 1.008) / 1.008) \times (273.15\ Kelvin + T) \qquad \text{Eqn. 1}$$

Taken from reference [1]

$$n_f = ((\Delta T / (273.15\ Kelvin + T)) \times 1.008) + 1.008 \qquad \text{Eqn. 2}$$

Derived from equation (1)

4. Take averages of n_f and ΔT. The DC offset written to the Thermal Sensor will be ΔT. It could be beneficial to take averages across certain temperature ranges, depending on the temperature range being optimized for. See Table 8 for examples of this averaging.

Table 6. Raw Data Example of Expected Temperature vs. Actual Temperature

Marlow Set (°C)	Thermo Couple Reading T (°C) (T)	Diode Reading using Thermal Sensor (°C) (actual)	ΔT (°C)= (actual – T)
5	5.00	10.50	5.50
15	15.00	19.75	4.75
25	25.00	29.50	4.50
35	35.00	39.00	4.00
45	45.00	48.75	3.75
55	55.00	58.50	3.50
65	65.00	68.25	3.25
75	75.00	78.25	3.25
85	85.00	88.00	3.00
95	95.00	97.75	2.75
105	105.00	107.50	2.50

Table 7. Ideality Factor Based on T and ΔT using Eq. (2)

T (°C)	ΔT (°C)	Ideality Factor n_f
5.00	5.50	1.0279
15.00	4.75	1.0246
25.00	4.50	1.0232
35.00	4.00	1.0211
45.00	3.75	1.0199
55.00	3.50	1.0188
65.00	3.25	1.0177
75.00	3.25	1.0174
85.00	3.00	1.0164
95.00	2.75	1.0155
105.00	2.50	1.0147

Table 8. Example of Ideality Factor and DC Offset Averages for MPC7448

	Overall	5–25°C range	35–65°C range	75–105°C range
ΔT avg =	3.70	4.92	3.63	2.88
n_f avg =	1.0197	1.0253	1.0194	1.0160

Appendix B Pseudocode

This appendix contains the pseudocode examples for all of the functions that make up the ATMS. The functions are broken up into the files that contain them, see Table 2 for a function hierarchy. Full versions of this code are publicly available under license from FSL.

env.c

```
./**************************************************************
 * adt7461_init()
 * This function initializes all the registers within the
 * ADT7461 thermal monitor to programmer specified values.
 * It also checks for the TOFFSET environment variable
 * and if found will set the DC offset of the ADT7461
 * to TOFFSET. If TOFFSET is not found it uses a default
 * offset determined by the processor type (47A or 48).
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 9/22/05
 * Return: void
 ^V^H*******************************************************/
void adt7461_init()
{
  ULONG da;                          // device address for Thermal Sensor
  ULONG temp;
  ULONG envalue;                     // environment variable holder
  char *negvalue;                    // negative environment variable holder

  // initialize the THERM global variables to 0 on boot up.
  ExtTHERM = 0; LocTHERM = 0;

  // Select the ADT7461 as the desired device to access on the I2C
  // bus by setting the correct device address.
  da = thermal sensor device address;
  gme_SetDevAddr( da );              // set I2C device address to thermal sensor
  Delay( 1000 );                     // Delay for 1000 ms

  // Set the Disable7461 global variable that controls
  // whether thermal monitoring is enabled/disabled
  Disable7461 = 0;
  if ( NULL != (TDISABLE environment variable) ) {
    temp = TDISABLE;
    if ( (temp == 1) || (temp == 0) )
      Disable7461 = temp;            // set global variable Disable7461 that will be used
                                     // and modified by the rest of the ATMS
  }

  // Enable and initialize thermal sensor
  if ( Disable7461 == 0 ) {
    write to thermal sensor on I2C bus to enable it;
  }
  else { // Put thermal sensor in Standby mode
    write to thermal sensor on I2C bus to disable it;
  }
```

```
// Set local temp high limit based on processor type
  if ( 0 == strcmp( CPUName, "MPC7447A" ) )
    temp = 0x34;                // 52degC
  else if ( 0 == strcmp( CPUName, "MPC7448" ) )
    temp = 0x2C;                // 44degC
  else
    temp = 0x55;                // power-on default
  write temp to Loc Temp High Lim register in thermal sensor;


  // Set external temp high limit based on processor type
  if ( 0 == strcmp( CPUName, "MPC7447A" ) )
    temp = 0x34;                // 52degC
   else if ( 0 == strcmp( CPUName, "MPC7448" ) )
    temp = 0x2C;                // 44degC
  else
    temp = 0x55;                // power-on default
  write temp to External Temp High Lim register in thermal sensor;
   …
  write desired values to the rest of the thermal sensor registers;
  …
// Set hysteresis value based on processor type
  if ( 0 == strcmp( CPUName, "MPC7447A" ) )
    temp = 0x04;
  else if ( 0 == strcmp( CPUName, "MPC7448" ) )
    temp = 0x05;
  else
    temp = 0x0A;
  write temp to hysteresis register in thermal sensor;


  // Set up ADT7461 DC offset based on TOFFSET environment variable
  // The .25degC resolution of the offsets are ignored for simplicity
  // and implementation sake
  if ( NULL != TOFFSET ) {
    envalue = TOFFSET converted from string to numeric value;
    write envalue to Offset register in thermal sensor;
  }
  else {
    //TOFFSET does not exist, assign DC offset to default value
    if ( 0 == strcmp( CPUName, "MPC7447A" ) ) {
      // for this implementation the MPC7447A was not calibrated, therefore
      // DC offset is just set to 0x00.
      envalue = 0x00;
      write envalue to Offset register;
    }
```

```
  else if ( 0 == strcmp( CPUName, "MPC7448" ) ) {
    // write to Offset High Byte register
    envalue = 0xFC;           // - 4degC
    write envalue to Offset register;
  }
 }
 return;
} // adt7461_init()
/***********************************************************
 * fan_init()
 * This function checks for the FANPWM environment variable
 * and if found writes to the TPWML and TPWMH registers that
 * control the CPU fan speed.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 9/22/05
 * Return: void
 * ^V^H*******************************************************/
void fan_init()
{
 ULONG pwmvalue;          // value for CPU fan register

 // in DINK32 the CPU fan is controlled by a PWM register.
 // Writing to this register different values will change the
 // fan speed.

 if ( NULL != FANPWM ) ) {
   // convert FANPWM to ULONG and massage in order to
   // write to PWM registers
   pwmvalue = FANPWM with necessary conversions;
   write pwmvalue to registers that control CPU fan speed;
 }
 else {
   // if environment variable not found then set fan to 100%
   pwmvalue = 0xFF;
   write pwmvalue to registers that control CPU fan speed;
 }
 return;
} // fan_init()
```

gme.c

```
/**********************************************************
 * check_limits()
 * This function checks to see if any thresholds have already
 * been exceeded during an enable of the thermal system.
 * Without this function if a threshold was already exceeded
 * then the thermal system would not recognize subsequent
 * rising/falling edges properly. This function is needed to
 * set the correct thermal system settings no matter what
 * temperature range the thermal system is enabled in.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 09/08/05
 * Return: void
 * ^V^H****************************************************/
void check_limits()
{
 ULONG statusRead;            // ADT7461 status register bits
 ULONG locTemp, extTemp;      // ADT7461 loc and ext thermal values
 ULONG temp;                  // used as temp to write static values
 int hid1, hidtemp;           // HID1 register values
 ULONG da;                    // device address for ADT7461
 ULONG pwmvalue;              // value for CPU fan register
 ULONG shutdownTemp;          // critical overheat temperature

 shutdownTemp = 0; pwmvalue = 0;
 da = 0; hid1 = 0; hidtemp = 0; temp = 0; statusRead = 0;

 // Select the ADT7461 as the desired device to access on the I2C
 // bus by setting the correct device address.
 da = thermal sensor device address;
 gme_SetDevAddr( da );        // set I2C device address to thermal sensor
 Delay( 1000 );               // Delay for 1000 ms

 locTemp = value read from Thermal Sensor Local Temp register;
 extTemp = value read from Thermal Sensor External Temp register;
 statusRead = value read from Thermal Sensor Status register;

 // set critical temperature limit
 if ( TSHUTDOWN env variable is defined)
```

```
  shutdownTemp = TSHUTDOWN;
else
  shutdownTemp = 100degC;


// Critical system threshold already exceeded
// Shut down system if temperature >= shutdownTemp
if ( (locTemp >= shutdownTemp) || (extTemp >= shutdownTemp) ) {


  PRINT("\n\tCritical overheat temperature detected!");
  PRINT("\n\tShutting down system...");


  power off system immediately;


}
// THERM threshold already exceeded
else if ( any of the THERM bits in statusRead are set )  {
  // Set the fan to 100%
  temp = 0xFF;
  write temp to CPU fan control registers to set to 100%;


  // set DFS2 bit in HID1 SPR to throttle CPU frequency
  hid1 = hid1_read();
  hidtemp = hid1;
  hid1_write( hid1 | 0x00400000 );


  // Increase THERM thresholds
  // Set the External THERM limit to shutdownTemp
  temp = shutdownTemp;
  write temp to Thermal Sensor External THERM Limit register;


  // Set the Local THERM limit to shutdownTemp
   temp = shutdownTemp;
  write temp to Thermal Sensor Local THERM Limit register;


  // switch interrupt INT0 polarity to rising edge to be able to catch the
  // next edge that will trigger an interrupt. This edge signifies the temperature
  // decreasing.
  configure interrupt vector for the interrupt INT0 to make its polarity rising edge;


}
```

```
  // THERM2 threshold already exceeded
  else if ( any of the High Temperature Limit bits in statusRead are set ) {
    // Set the fan to 100%
    temp = 0xFF;
    write temp to CPU fan control registers to set to 100%;

    // switch interrupt INT0 polarity to rising edge to be able to catch the
    // next edge that will trigger an interrupt. This edge signifies the temperature
    // decreasing.
    configure interrupt vector for the interrupt INT0 to make its polarity rising edge;


  }
  // no temperature thresholds have been exceeded
  else {
    // set the fan to FANPWM if it is defined, otherwise set to 50%
    if ( NULL != FANPWM ) ) {
      // convert FANPWM to ULONG and massage in order to
      // write to PWM registers
      pwmvalue = FANPWM with necessary conversions;
      write pwmvalue to registers that control CPU fan speed;
    }
    else {
      // if environment variable not found then set fan to 50%
      pwmvalue = 0xAA;
      write pwmvalue to registers that control CPU fan speed;
    }

    // switch INT0 polarity to falling edge in case it had been
    // changed elsewhere but a disable of the ATMS prevented the interrupt
    // from switching the polarity back when threshold was crossed
    configure interrupt vector for the interrupt INT0 to make its polarity falling edge;
  }

  return;
} // check_limits()
```

```
/************************************************************
 * ct_exec
 * Auxilliary function for the "ct" command called by par_gme.
 * This function handles all of the possible "ct" commands and
 * performs the proper function depending on user's command line
 * arguments. It also handles enabling and disabling the ATMS
 * and ensuring that the proper thermal thresholds are set up.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 09/08/05
 * Return: void
 * ^V^H*****************************************************/
void ct_exec( char *args )
{
  char      b;                    // holds read bytes from command line arguments
  ULONG  da, test;                // device address and valid argument test
  char*     token;                // tokens for strtok()
  char      optstr[20] = "";      // array containing valid flags
  ULONG  datastr[20];             // array containing valid hex values from command line
  int       i, j;                  // LCVs
  ULONG  temp;                    // used as temp to write static values to Thermal Sensor
  int hid1;                       // HID1 register value
  int hidtemp;                    // temp when modifying HID1 register
  ULONG msrCheck;                 // holds bits read from MSR register

  msrCheck = 0; hidtemp = 0; hid1 = 0;
  temp = 0; i = 0; j = 0; da = 0; test = 0;

  // Select the ADT7461 as the desired device to access on the I2C
  // bus by setting the correct device address.
  da = thermal sensor device address;
  gme_SetDevAddr( da );           // set I2C device address to thermal sensor
  Delay( 1000 );                  // Delay for 1000 ms

  // tokenize argument string in order to process each flag/option one at a
  // time and to check for invalid entries
  if( (token = strtok(args, " ")) != NULL ) {
    // make sure that argument is a valid flag
    if( (b = arg_getopts( &token, "toxlcgaders", 0, &da )) != 0 ) {
      // since -a, -d, -e are to be used separately
      // check for them first and perform direct operations and return
```

```
switch (b) {
        // write default values to all valid registers
        // see ADT7461 datasheet pg 14 for power on defaults
        case 'a':
          write power-on default values to all the registers in Thermal Sensor;

          // use function to print out registers in the Thermal Sensor
          print_adt7461_registers();
          return;
        case 'd': // disable device
          // Disable interrupt vectors so they are no longer triggered
          Disable7461 = 1;      // set global disable variable so that all other functions know
                                // that the ATMS is disabled
          mpicIntDisable(0);    // disable INT0 interrupt vector
          mpicIntDisable(1);    // disable INT1 interrupt vector

          // Read current Configuration register value then OR the standby bit
          temp = value read from Thermal Sensor Configuration register;

          // Put ADT7461 in standby mode
          temp = temp | 0x40;           // set standby bit
          write temp to Thermal Sensor Configuration register;

          // Set the fan to FANPWM if environment variable is defined,
          // otherwise set to 100%
          fan_init();

          // Since no longer monitoring if DFS is enabled then set
          // THERM thresholds to previous values and disable DFS mode

          // Read the HID1 register to obtain status of the DFS2 bit
          hid1 = hid1_read();
          hid1 &= 0x00400000;

          if ( hid1 ) {
            // Reset DFS2 bit in HID1 SPR to set CPU core freq to max
            hid1 = hid1_read();
            hidtemp = hid1;

            // clear DFS bit in HID1 and write back to HID1
            hid1_write( hid1 & 0xFFBFFFFF );

            // ExtTHERM and LocTHERM are globals defined in ct_exec
            // whenever the user uses the “ct” command to change the THERM
            // limits. These globals are used to refresh the previous values when
```

```
    // the limits are automatically changed by the ATMS
    // Set the External THERM limit back to default
    if ( ExtTHERM != 0 )
      temp = ExtTHERM;
    else
      temp = 0x55;
    write temp to External THERM Limit register in Thermal Sensor;

    // Set the Local THERM limit back to default
    if ( LocTHERM != 0 )
      temp = LocTHERM;
    else
      temp = 0x55;
    write temp to Local THERM Limit register in Thermal Sensor;
  }

  // print all register values in Thermal Sensor
  print_adt7461_registers();
  return;
case 'e': // enable device
  // Read current Configuration register value then AND out the standby bit
  temp = value read from Thermal Sensor Configuration register;
  temp = temp & 0xBF;       // clear Standby bit

  // Take ADT7461 out of standby mode
  write temp to Thermal Sensor Configuration register;

  // delay to allow thermal sensor to come out of standby and refresh its registers
  Delay( 2000 );

  // Check to see if interrupts have been enabled by reading
  // the MSR register bit 16. MSR is a register that contains
  // a bit that is ‘0’ if interrupts are disabled and ‘1’ if enabled
  msrCheck = msr_read();
  msrCheck = (msrCheck & 0x00008000) >> 15;// pull out bit
  if ( msrCheck ) {
    check_limits();             // if interrupts are enabled then need to check what the current
                                // temperature readings are and set the appropriate thresholds
  }

  // Enable interrupt vectors so they are triggered when a threshold is passed
  Disable7461 = 0;              // set global disable variable so that all other functions
                                // know that the ATMS is enabled
  mpicIntEnable(0);             // enable INT0 interrupt vector
  mpicIntEnable(1);             // enable INT1 interrupt vector

  // print all the registers in the Thermal Sensor
```

```
            print_adt7461_registers();


            return;
    }
    // Process all other commands…
    // if flag is other than -a,-d,-e then try to
    // find a valid hex value that will be written to register
    if( ((token = strtok(NULL, " ")) != NULL) && (b != '?') ) {
            if( (arg_getvalue(&token, &test, 16)) == SUCCESS ) {
             // if flag and value are valid place both
             // into their appropriate arrays.
             *(optstr + j) = b;
             *(datastr + j) = test;
             j++;
            }
    }
  }
}

// continue searching arg string until no more
// valid tokens are found
while( (token = strtok(NULL, " ")) != NULL ) {
  // make sure that argument is a valid flag
  if( (b = arg_getopts( &token, "toxlcgaders", 0, &da )) != 0 ) {
    // if flag is other than -a,-d,-e then try to find a
    // valid hex value that will be written to register
    if( ((token = strtok(NULL, " ")) != NULL) && (b != '?') ) {
            if( (arg_getvalue(&token, &test, 16)) == SUCCESS ) {
             // if flag and value are valid place both into their appropriate
             // arrays.
             *(optstr + j) = b;
             *(datastr + j) = test;
             j++;
            }
    }
  }
}

// loop through the number of valid operations
// indicated by j and perform necessary operations
for ( i = 0; i < j; i++ ) {
  switch (optstr[i]) {
    // Set the External THERM limit
    case 't':
            write datastr[i] to External THERM Limit register;
```

```
            ExtTHERM = datastr[i];  // store user changes in order to refresh later
            break;
     // Set the Local THERM limit
    case 'o':
            write datastr[i] to Local THERM Limit register;
            LocTHERM = datastr[i];  // store user changes in order to refresh later
            break;
    // Set the External Temperature High Limit High Byte
    case 'x':
            write datastr[i] to External Temp High Limit register;
            break;
    // Set the Local Temperature High limit
    case 'l':
            write datastr[i] to Local Temperature High Limit register;
            break;
    // Set the conversion rate of the ADT7461
    case 'c':
            write datastr[i] to Conversion Rate register;
            break;
    // Set the THERM Hysteresis value
    case 's':
            write datastr[i] to THERM Hysteresis register;
            break;
    // Set the Consecutive ALERT value
    case 'r':
            write datastr[i] to Consecutive ALERT register;
            break;
    // Set the Configuration Register value
    case 'g':
            write datastr[i] to Configuration register;
            break;
    default:  return;
   }
  }
  // print all of the registers within the Thermal Sensor
  print_adt7461_registers();


  return;
} // ct_exec()
```

```
/*************************************************************
 * dt_exec
 * Auxilliary function for "dt" command called by par_gme.
 * This function displays the current temperature reading
 * from the ADT7461 and displays this value in both hex
 * and Celcius.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 07/29/05
 * Return: void
 * ^V^H****************************************************/
void dt_exec( )
{
  ULONG fb, sb;        // first byte and second byte of external temp
  ULONG lb;            // local temperature byte
  int   sbm;           // second external byte modified to decimal value
  ULONG da;            // device address for ADT7461

  da = 0; fb = 0; sb = 0; lb = 0; sbm = 0;

  // Select the ADT7461 as the desired device to access on the I2C
  // bus by setting the correct device address.
  da = thermal sensor device address;
  gme_SetDevAddr( da );      // set I2C device address to thermal sensor
  Delay( 1000 );             // Delay for 1000 ms

  lb = value read from Local Temperature register in Thermal Sensor;
  fb = value read from External Temp High Byte register in Thermal Sensor;
  sb = value read from External Temp Low Byte register in Thermal Sensor;

  // Only the first two bits of the second byte are used to
  // determine the .25 degree resolution. Therefore divide
  // the 8-bits read by 2.56 to get the decimal equivalent
  // we are looking for. See 7461 datasheet pg. 10.
  // Ex:
  // sb = 0b01000000 (0x40 or 64 decimal)
  // (sb / 2.56) = (64 / 2.56) = 25
  // 25 is the degree resolution
  sbm = (int) (((float) sb) / 2.56); // divide by 2.56 to get decimal digits
```

```
  // print temperature values to screen (stdout)
  PRINT("\n\t   Register values (hex): 0x01: %-2.2X\n"
      "                                        0x10: %-2.2X", fb, sb);
  PRINT("\n\t Local Temperature (degrees C):   %-d.00", lb);
  PRINT("\n\tRemote Temperature (degrees C): %-2.2d.%-2.2d\n\n", fb, sbm);


  return;
} // dt_exec()
/*************************************************************
 * print_adt7461_registers
 * Function used by ct_exec to print out the registers
 * inside the Thermal Sensor.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 09/02/05
 * Return: void
 * ^V^H*********************************************************/
void print_adt7461_registers()
{
  ULONG da;                   // device address for Thermal Sensor
  ULONG temp;


  temp = 0; da = 0;


  // Select the ADT7461 as the desired device to access on the I2C
  // bus by setting the correct device address.
  da = thermal sensor device address;
  gme_SetDevAddr( da );            // set I2C device address to thermal sensor
  Delay( 1000 );                   // Delay for 1000 ms


  // display current register settings.
  // can be used to verify changes.
  PRINT("\n\tADT7461 Register Settings");
  PRINT("\n\t-----------------------------------------------------");
  PRINT("\n\tRegister\tName                    \tValue");
  PRINT("\n\t--------\t---------------------------\t-----");


  read each register in the Thermal Sensor and print out name and value;
```

```
 //Ex.
 //          gme_I2C_acc( (unsigned long) 0x02, &temp, B_ACCESS, GME_R );
 //          PRINT("\n\t  0x02  \tStatus\t\t\t\t0x%-2.2X\n", temp);


 return;
} // print_adt7461_registers()
```

mpic1.c

/***
 * **adt7461_interrupt_init**
 * This routine sets up the TICK register settings and fan
 * speed for the ATMS.
 * **This app note contains pseudocode instead of the full version.**
 * **DINK32 with the full code is publicly available under license from FSL.**
 *
 * Author: Brandon Ade
 * Date: 09/07/05
 * Return: void
 ^V^H***/

```
void adt7461_interrupt_init()
{
 ULONG tisrinit;       // value to write to TISR register. The TISR register
                       // contains the bits that control the settings of the
                       // interrupt vectors and how they are handled
 tisrinit = 0;

 // If Disable7461 global is not set then check for
 // limits and initialize thermal system
 // Disable7461: 0=enabled, 1=disabled
 if ( !Disable7461 ) {
   check_limits();     // if ATMS is enabled then check temperature thresholds
 }

 // Set up TISR register at address 0x40 in the TICK register set
 // to allow for THERM flag to trigger INT[1] and ALERT/THERM2 flag
 // to trigger INT[0]
 tisrinit = 0x24;
 write tisrinit to TISR (interrupt settings) register;

 return;
} // adt7461_interrupt_init()
```

```
/****************************************
 * ISR_INT0
 * ALERT/THERM2 interrupt handler
 * This interrupt handler is part of the ATMS that attempts
 * to cool the processor using a combination of CPU throttling
 * and CPU fan control.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 08/18/05
 * Return: void
^V^H****************************************/
void ISR_INT0(ULONG vector)
{
  int hid1;             // HID1 read value
  int hidtemp;          // temp used to write to HID1
  ULONG srcVal;         // used when reading polarity of INT[0]
  ULONG srcAddr;        // address of interrupt vector 0
  int polarity;         // polarity of interrupt vector 0
  ULONG da;             // device address of thermal sensor
  ULONG temp;

  hid1 =0; hidtemp = 0; srcVal = 0; srcAddr = 0;
  polarity = 0; da = 0; temp = 0;

  // Select the ADT7461 as the desired device to access on the I2C
  // bus by setting the correct device address.
  da = thermal sensor device address;
  gme_SetDevAddr( da );          // set I2C device address to thermal sensor
  Delay( 1000 );                 // Delay for 1000 ms

  // Find current polarity of vector 0 to determine
  // rising or falling edge trigger. This code is DINK32 specific.
  // For other systems just determine the current polarity of the
  // interrupt
  srcAddr = mpicVecTable[vector].srcAddr;
  srcVal = sysMpicRegRead(srcAddr);                      // read vector register
  polarity = (srcVal & MPIC_MPIC_IVPR0_P) >> 24;   // parse polarity bit

  // if falling edge is detected
  if ( 0 == polarity ) {
    // Turn the fan full on to try and cool processor
    // Set the fan to 100%
    temp = 0xFF;
    write temp to CPU fan control registers to set to 100%;
  }
  else {       // else rising edge
     // set the fan to FANPWM if it is defined, otherwise set to default 50%
    if ( NULL != FANPWM ) ) {
      // convert FANPWM to ULONG and massage in order to
      // write to PWM registers
      temp = FANPWM with necessary conversions;
      write temp to registers that control CPU fan speed;
    }
```

```
  else {
    // if environment variable not found then set fan to 50%
    temp = 0xAA;
    write temp to CPU fan control registers.
  }

  // Read the HID1 register to obtain status of the DFS2 bit
  hid1 = hid1_read();
  hid1 &= 0x00400000;              // parse out DFS bit

  if ( hid1 ) {
    // If DFS is enabled disable it.

    // Reset DFS2 bit in HID1 SPR to set CPU core freq to max
    hid1 = hid1_read();
    hidtemp = hid1;
    hid1_write( hid1 & 0xFFBFFFFF );        // clear DFS2 bit

    // ExtTHERM and LocTHERM are globals defined in ct_exec
    // whenever the user uses the "ct" command to change the THERM
    // limits. These globals are used to refresh the previous values when
    // the limits are automatically changed by the ATMS
    // Set the External THERM limit back to previous values
     if ( ExtTHERM != 0 )
      temp = ExtTHERM;
    else
      temp = 0x55;
    write temp to External THERM Limit register in Thermal Sensor;

    // Set the Local THERM limit back to previous values
    if ( LocTHERM != 0 )
      temp = LocTHERM;
    else
      temp = 0x55;
    write temp to Local THERM Limit register in Thermal Sensor;
  }
 }
 // In order to catch the next rising/falling edge, the polarity of the
 // interrupt vector must be swapped. It is simply the inverse of its
 // current state.
 polarity = (srcVal & MPIC_MPIC_IVPR0_P) >> 24;   // parse polarity bit
 polarity = (polarity == 0) ? 1 : 0;               // swap polarity bit
 write to register that controls the polarity interrupt vector 0;

 return;
} // ISR_INT0()
```

```
/****************************************
 * ISR_INT1
 * THERM interrupt handler
 * This interrupt handler is part of the thermal
 * monitoring system that attempts to cool the
 * processor using a combination of CPU throttling
 * and CPU fan control.
 * This app note contains pseudocode instead of the full version.
 * DINK32 with the full code is publicly available under license from FSL.
 *
 * Author: Brandon Ade
 * Date: 08/18/05
 * Return: void
 ^V^H****************************************/
void ISR_INT1(ULONG vector)
{
 int hid1;                  // HID1 read value
 int hidtemp;               // temp used to write to HID1
 ULONG da;                  // device address of thermal sensor
 ULONG locTemp, extTemp;    // ADT7461 loc and ext thermal values
 ULONG shutdownTemp;        // critical overheat temperature
 ULONG temp;

 shutdownTemp = 0; locTemp = 0; extTemp = 0;
 hid1 = 0; hidtemp = 0; da = 0; temp = 0;

 // Select the ADT7461 as the desired device to access on the I2C
 // bus by setting the correct device address.
 da = thermal sensor device address;
 gme_SetDevAddr( da );      // set I2C device address to thermal sensor
 Delay( 1000 );             // Delay for 1000 ms

 locTemp = value read from Thermal Sensor Local Temp register;
  extTemp = value read from Thermal Sensor External Temp register;

 // set critical temperature limit
 if ( TSHUTDOWN env variable is defined)
   shutdownTemp = TSHUTDOWN;
 else
   shutdownTemp = 100degC;

 // Critical system threshold exceeded
 // Shut down system if temperature >= shutdownTemp
 if ( (locTemp >= shutdownTemp) || (extTemp >= shutdownTemp) ) {

   PRINT("\n\tCritical overheat temperature detected!");
   PRINT("\n\tShutting down system...");

   power off system immediately;

 }
 else {
   // THERM threshold exceeded, enable DFS
```

```
    // set DFS2 bit in HID1 SPR to throttle CPU
    hid1 = hid1_read();
    hidtemp = hid1;
    hid1_write( hid1 | 0x00400000 );            // set DFS2 bit

    // Increase THERM thresholds in Thermal Sensor

    // Set the External THERM limit to shutdownTemp
    temp = shutdownTemp;          // critical temperature limit
    write temp to External THERM Limit register in Thermal Sensor;

    // Set the Local THERM limit to shutdownTemp
    temp = shutdownTemp;          // critical temperature limit
    write temp to Local THERM Limit register in Thermal Sensor;
  }

  return;
} //ISR_INT1
```

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