Freescale Semiconductor
Application Note

Document Number: AN3414
Rev. 1, 03/2007

Toaster Oven Control System Using MC9S08QD2

by: Samuel Quiroz Corkidi
RTAC Americas

1 Introduction

Traditionally, electric toaster ovens have implemented temperature control using discrete components, including solenoids, thermostats, and thermal fuses. Some of these components may be expensive and unreliable. These components can be replaced by an embedded control system. By using the appropriate control method and components, system costs can be reduced and performance increased. Embedded systems allow you to add new functions without replacing the whole system, which reduces weight and space requirements and eases component replacements.

This document helps users convert a discrete control system to an embedded system. Using a domestic toaster oven as an example, it also demonstrates that an on-off control system can be implemented on a low-end 8-bit MCU. This embedded control system is based on the low-cost, high-performance MC9S08QD2, a member of the HCS08 family of 8-bit microcontroller units (MCUs). Two potentiometers give you control of oven temperature and toasting time. By pressing a push button, you can start or stop the device. This design also uses a low-cost temperature sensor that provides a more accurate on-off feedback control system.

Contents

2 Design Requirements

2.1 System Overview

The user can specify the temperature, toasting time, and start or stop the heating process at any time. An indicator light informs the user the device is heating, while a sound generated by the device indicates the process is complete.

To provide feedback to the control system, the system has a temperature sensor. Due to the voltage operation difference between the heating element and the MCU, there is a coupling stage (capable of managing standard domestic line voltage levels) to switch the heating device on and off.

3 Modes of Operation

This system is intended to work in two modes. The first mode is toaster mode, in which the user specifies the desired temperature and the desired heat time. After this time has elapsed, the toaster turns off automatically and informs the user by making a beep sound. The user may also stop the device at any time by pressing the pushbutton.

The second mode is oven mode, which is entered when the user turns off the time knob. In this mode, the user doesn't specify a cooking time, but only the desired temperature. Therefore, the oven heats to the desired temperature until the user turns it off. Figure 1 shows the user inputs.

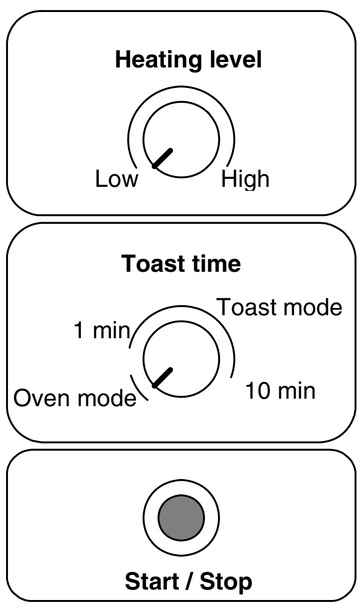

Figure 1. User Inputs

4 Hardware Implementation

4.1 User Inputs

The time and heat potentiometers are read by the on-chip analog-to-digital converter on the MC9S08QD2. The pushbutton is connected to a general input with the internal pull-up resistor enabled.

4.1.1 Temperature Sensor

There are several kinds of temperature sensors of varying price, sensitivity, temperature range, and size. Because high temperature sensors are generally more expensive, this design uses a LM35 low-cost linear temperature sensor.

The LM35 series is a precision integrated-circuit temperature sensor with an output voltage linearly proportional to the celsius (centigrade) temperature. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±3/4°C over full -55° to +150°C temperature range. The LM35 is rated to operate over a -55° to +150°C temperature range. The voltage output of the sensor is directly proportional to the temperature (10 mV/°C) and is read by one of the ADC inputs.

Because this sensor doesn’t support high temperatures inside the toaster oven, it cannot be placed inside the oven. It can, however, be placed near a hot surface of the device where you can guarantee the maximum temperature supported by the sensor is not exceeded.

4.1.2 Status Indicators

An LED and a speaker connected to the microcontroller show the status of the toaster oven. A general-purpose NPN bipolar junction transistor drives the necessary current to the LED and the speaker. Because the MC9S08QD2 is limited to eight pins, the LED and speaker output share a common pin. This is not a problem because the LED works with direct current and the speaker works with alternating current. To turn on/off the LED, the program sets the pin at the desired level because this does not generate any sound on the speaker. To generate a sound, it toggles the output to create an audible signal on the speaker. When the speaker is generating sound, the LED flashes at the sound frequency.

The LED/speaker is connected to PTA4, but this pin shares the background BKGD/MS function used to enter active background mode. A jumper or a switch is used to select PTAD4 or BKGD/MS.

Active background mode is entered when the BKGD/MS pin is low at the rising edge of reset. After entering active background mode, the CPU is held in a suspended state while it waits for serial background commands instead of executing instructions from the application program.

When the pin function selected is PTAD4, a pull-up resistor is used to avoid entering active background mode after a power-on-reset (POR).

4.1.3 Output Stage

The heating element (usually a resistor load) operates with domestic line voltage levels (110/220 V_{AC}). This means you must use some sort of external devices to switch the heater on and off. Use an electromechanical relay capable of managing the desired heater current or an opto-isolator to drive a TRIAC to switch the heating device.

Coupling and power stages should be used to manage domestic line voltages. You are responsible for selecting a device that suits your needs.

4.1.4 Electrical Schematic

Figure 2 shows the electrical schematic used on the design.

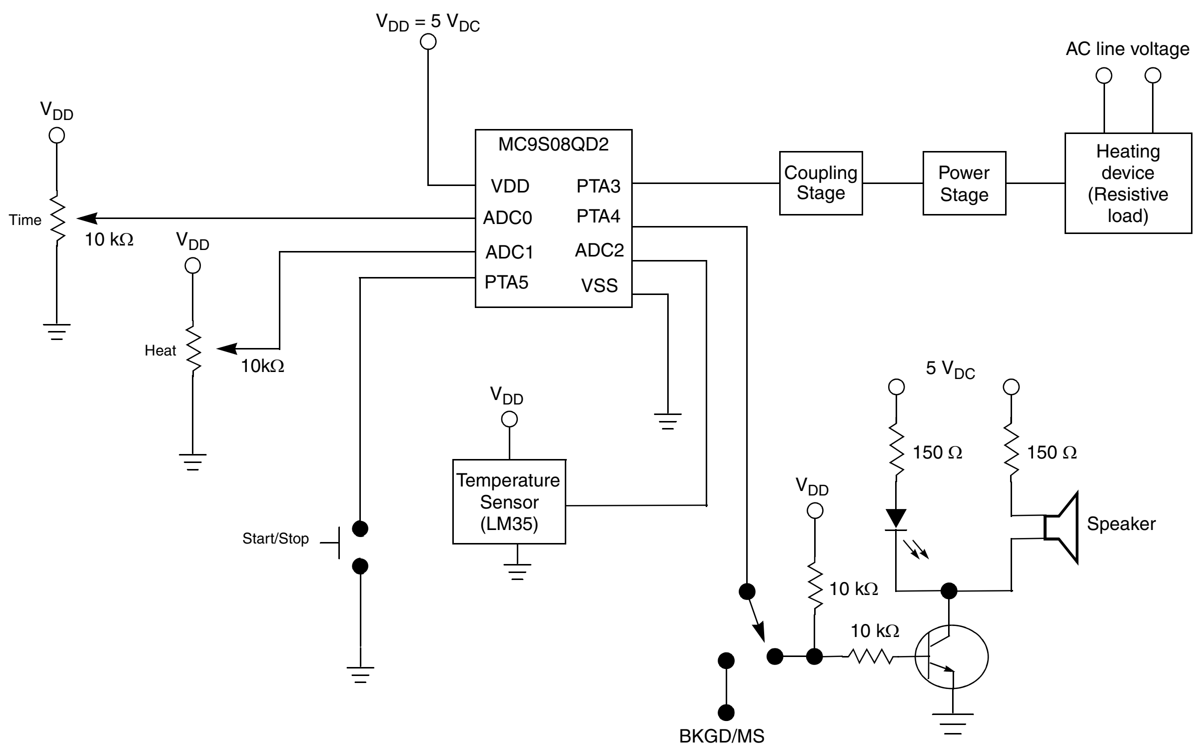

Figure 2. Electrical Schematic

5 Development Tools

The programming language used for this application is C. This application was developed using CodeWarrior 5.1 with the MC9S08QD2/4 patch properly installed.

6 Software Implementation

6.1 On-off Control

On-off control is the simplest kind of control and is used in almost all domestic electric toaster ovens. When the temperature of the oven is lower than the desired temperature, the heater is turned on. After the oven's temperature has reached the desired temperature, the heater is turned off. The heater cannot vary the heat intensity; it only turns the oven on or off (Figure 3).

This kind of control system presents a problem of temperature oscillating around the set-point. The turn-on temperature differs slightly from the turn-off temperature. This difference is called hysteresis and prevents the oven from switching rapidly and unnecessarily when the temperature is near the set-point.

On-off control can be used for non-critical applications, when a slight variation in the output is acceptable. Control systems like this are cheap, effective and can represent a good design choice.

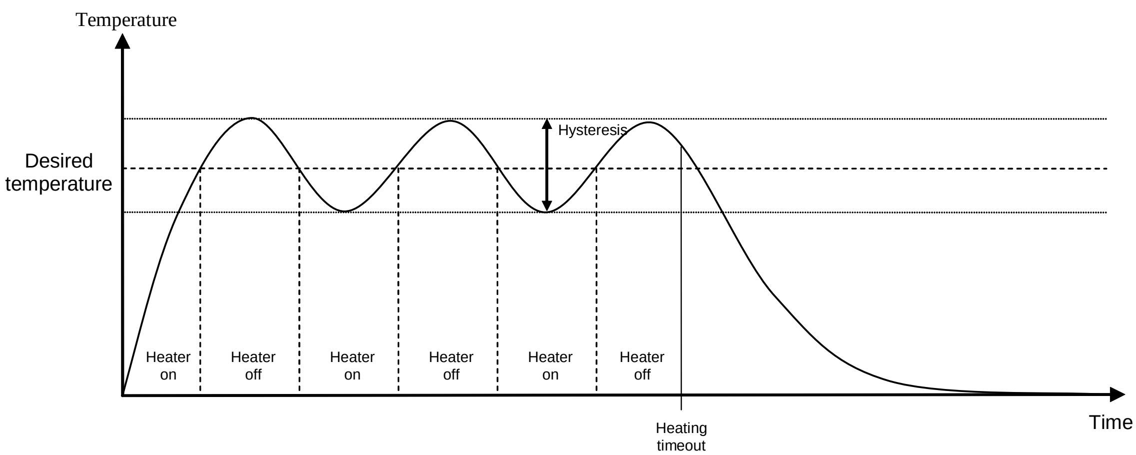

Figure 3. On-off System Behavior

7 Execution Flow and System States

The operation of the system can be described with a simple state machine. As shown on Figure 4, after startup, you can divide the operation of the device into three main states.

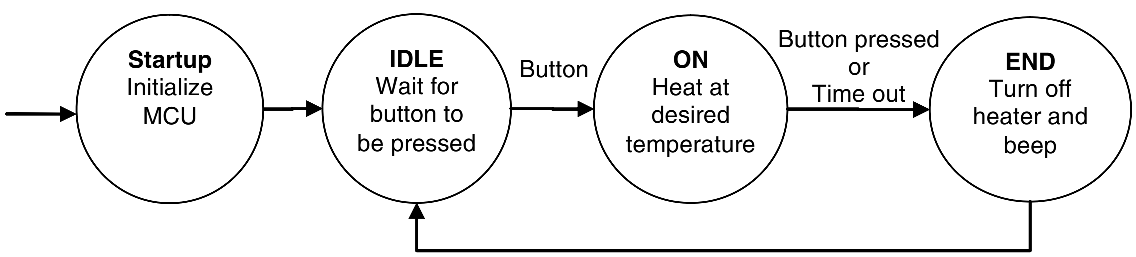

Figure 4. State Machine

The MCU must be configured at startup before entering the main loop. This includes initializing configuration registers, system clock, ADC, and general-purpose inputs/outputs (GPIOs). After startup, the application enters an infinite loop that executes the state machine.

The idle state waits for the button to be pressed to change to the on state so the toaster oven can start heating. In the on state, the system reads the user inputs to select the proper operation mode (oven or toaster) and starts heating until the desired temperature is reached. The on-off control algorithm is performed during this state. The flow diagram for the on state is shown in Figure 5. The machine only changes to end state when a timeout occurs or a button is pressed.

System states are separated into functions. During the application's main loop, the state machine calls the function depending on the actual state. The program also checks if an RTI overflow has occurred or if a button is pressed at that moment. No interrupts are used in the program. Because this is a non-critical system, a polling method is used instead.

The start/stop button is read in at least two states; therefore, you need a method to determine if the button was pressed to avoid changing the state repeatedly. To avoid this problem,the software uses flags (variables) instead of reading the actual push button status. After the button has been pressed, a flag is set to alert you of this. When you release the button, the previous flag is cleared. To enhance this functionality, the program uses a debounce timer to avoid triggering false mechanical rebounds from the push button.

The real time interrupt (RTI) of the MC9S08QD2 is used as a time base. It is configured to overflow every 1.024 seconds. In this way, the program knows that one second has elapsed and checks if the desired time has elapsed.

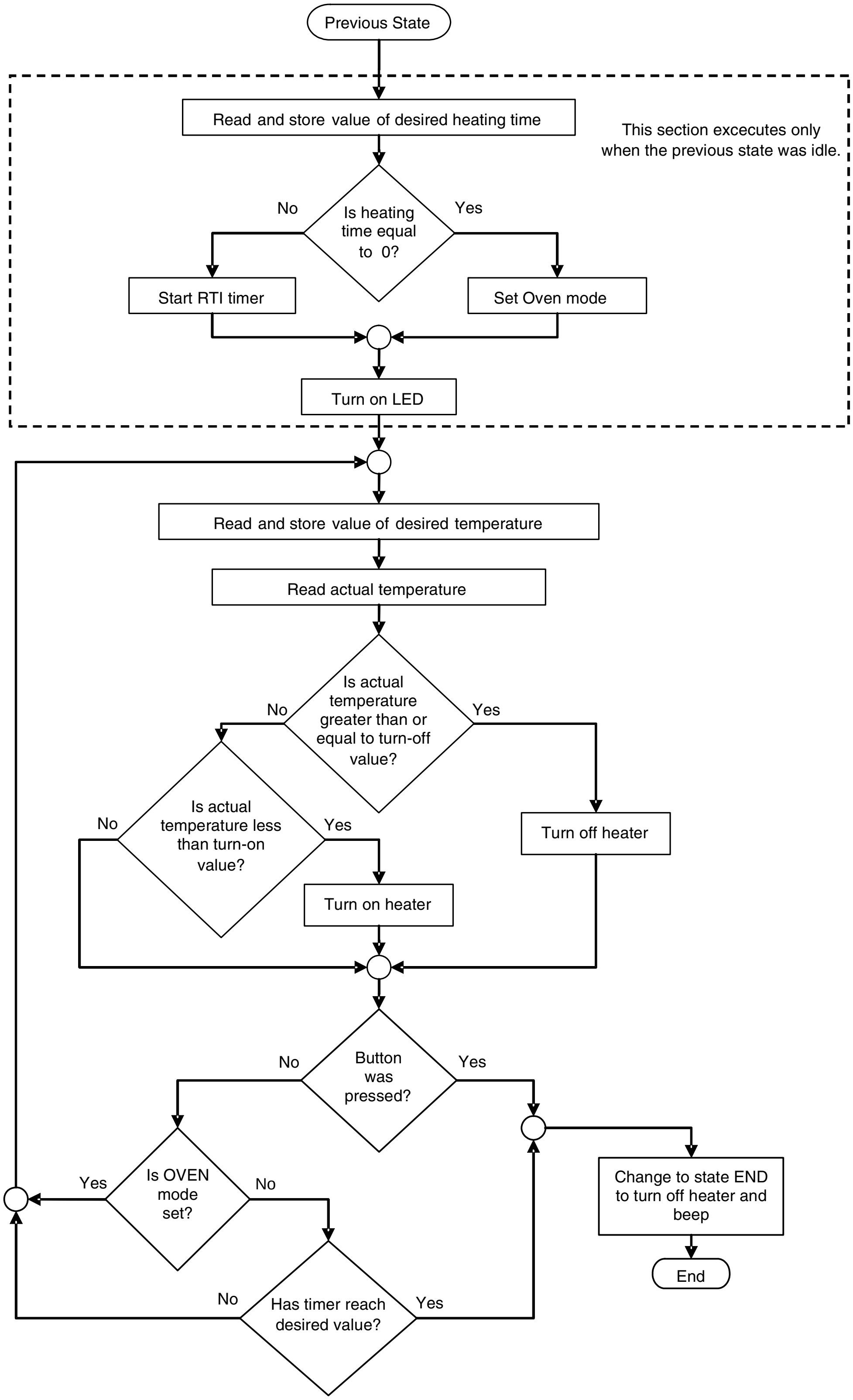

Figure 5. ON State Flow Diagram

Figure 6 shows the flow diagram of the END state in which the heater is turned off. A 2 kHz sound is then generated by the speaker output pin. The timer/pulse-width modulator of the MC9S08QD2 generates the audible tone, and the RTI counts the duration of the sound.

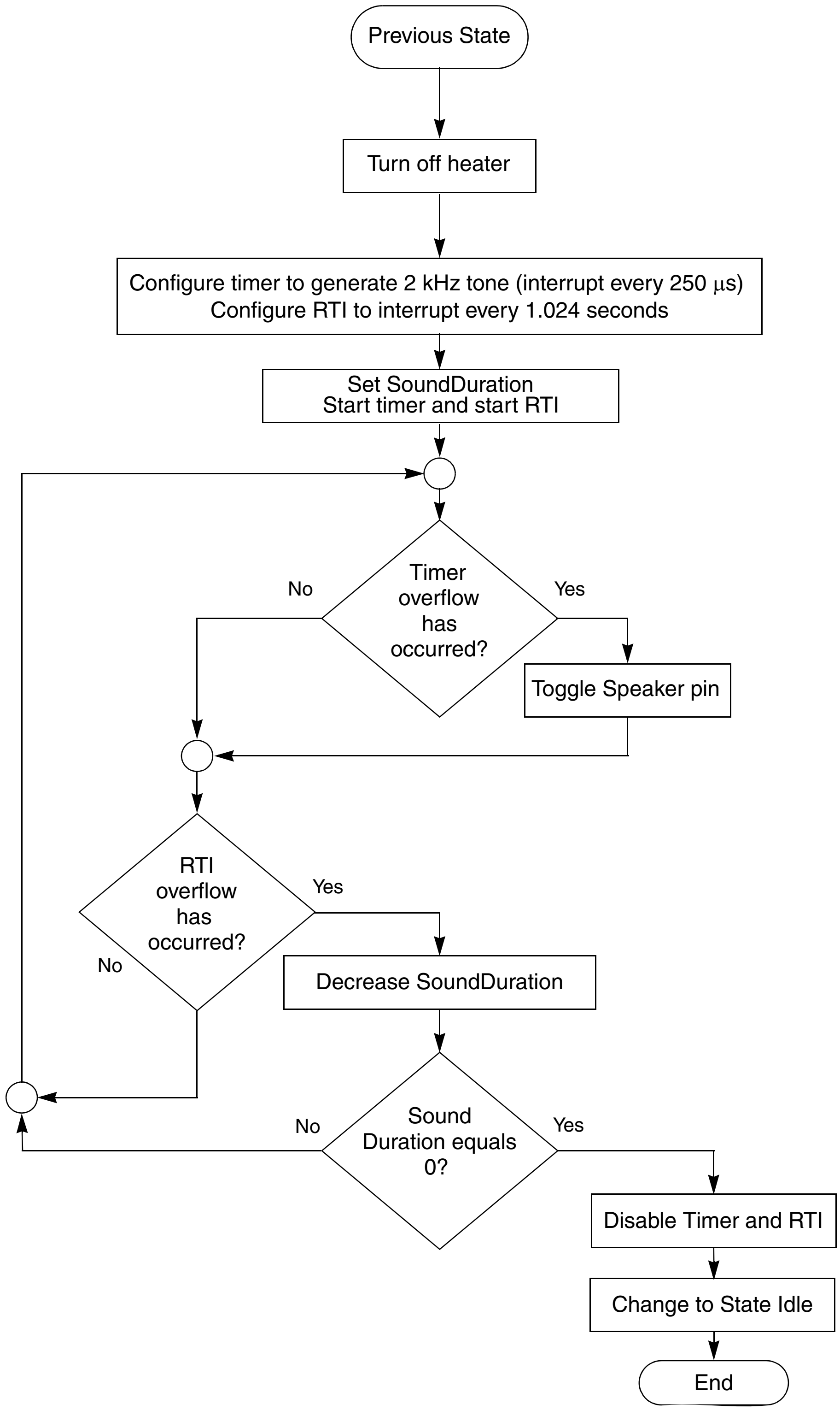

Figure 6. END State Flow Diagram

7.1 Benefits of the Solution

There are many advantages to using an embedded control system over older control system methods. Analog control systems can be difficult and costly to modify or update after they are designed and finished. Some of the elements in the system must be replaced to change the system behavior.

However, embedded control systems can be easily updated or modified by changing some lines of code. Many pieces of software (such as functions) can be reused on different systems, reducing development cost and time.

With new digital technologies, software samples and development tools, designers can quickly build up embedded solutions and replace discrete control systems with embedded control systems.

8 Testing and Validation

The system was tested by placing the sensor near the bottom of an ordinary toaster oven. On the initial tests, when the temperature approached the set-point, the heater was switching on and off repeatedly because the turn-on and turn-off thresholds were too close to each other. This was fixed by specifying a wider hysteresis gap.

9 Conclusion

This application note shows designers interested but not familiarized with digital embedded systems how to implement a simple on-off control system with a low-end 8-bit microcontroller. It serves as a basic guide that can be easily modified and enhanced to suit designer and user needs. This solution, however, does not represent a fully-validated end user product, but it should serve more as a primer for those interested in embedded systems and their many advantages.

10 References

- Barr, Michael. Closed-Loop Control Embedded Systems Programming, August 2002 , pp. 55-56.
- D.H. Williams, Charles. *Types of Feedback Control*.
- LM35 Precision Centigrade Temperature Sensors data sheet.
- Ochoa Alfredo, Lara Alex & Gonzalez Gabriel. *High Resolution Digital Dimmer.* AND8011.

THIS PAGE IS INTENTIONALLY BLANK

How to Reach Us:

Home Page:
www.freescale.com

Web Support:
http://www.freescale.com/support

USA/Europe or Locations Not Listed:
Freescale Semiconductor, Inc.
Technical Information Center, EL516
2100 East Elliot Road
Tempe, Arizona 85284
+1-800-521-6274 or +1-480-768-2130
www.freescale.com/support

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
www.freescale.com/support

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@freescale.com

For Literature Requests Only:
Freescale Semiconductor Literature Distribution Center
P.O. Box 5405
Denver, Colorado 80217
1-800-441-2447 or 303-675-2140
Fax: 303-675-2150
LDCForFreescaleSemiconductor@hibbertgroup.com

Document Number: AN3414
Rev. 1
03/2007