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H8/300L

Implementation of I²C (Port) to Three I²C Devices (3I2Cport)

Introduction

This application note provides an overview of the I²C bus interface. It also demonstrates how to integrate and interface multiple I²C devices to the H8/38024 SLP series through software control of its two general I/O pins:

- Microchip 24AA16 16K I²C Serial EEPROM (read/write)
- Maxim MAX6626 12-bit Temperature Sensor (read/write)
- MAX6953EPL 2-wire Interfaced 4-digit 5 x 7 Matrix LED Display Driver (write only)

Target Device

H8/38024 SLP Series
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1. I²C™ Interface Overview

The I²C bus uses a two-wire interface consisting of a serial data line (SDA) and a serial clock line (SCL) to exchange information between devices connected to the bus. Each device on the bus has its own unique address and can operate as a transmitter or receiver (depending on its particular function). Devices are further categorized as Masters or Slaves. A Master is defined as a device that initiates, controls (generates all framing and clock signals), and terminates a transfer whereas a Slave is any device addressed by a Master.

It is noted that different I²C devices will have slightly different protocols. This application note describes an I²C interface comprising of a bus master (H8/38024 SLP MCU) and three slave devices (Microchip 24AA16 16K I²C Serial EEPROM, Maxim MAX6626 12-bit temperature sensor and MAX6953EPL 2-wire interfaced 4-digit 5 x 7 Matrix LED Display Driver). In this simple interface, the temperature converted from the MAX6626 will be displayed and can also be stored in the EEPROM. Note that the I²C interface is simulated using software to control two general I/O pins (P70→SDA & P80→SCL) of the H8/38024 SLP MCU. The SDA and SCL pins of these devices are directly connected to P70 and P80 of the MCU respectively. Figure 1 shows the system block diagram.

![System Block Diagram](image)

The address of each device is summarized in Table 1 (This discussion is limited to the I²C 7-bit addressing mode). Each device has a unique 7-bit I²C address so that the master knows which device it is communicating with. Typically, the upper address lines are fixed while the lower address lines are set by hardware. For the case of three lower address lines (A2, A1, A0), there are up to eight different combinations. Therefore, up to a maximum of eight identical devices can be interfaced on the same bus. To interface another I²C device, the SDA and SCL pins must be connected to the bus with a unique address assigned to it.

<table>
<thead>
<tr>
<th>Device</th>
<th>Address (Hexadecimal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microchip 24AA16 EEPROM</td>
<td>A0 – Block 0</td>
</tr>
<tr>
<td></td>
<td>A2 – Block 1</td>
</tr>
<tr>
<td></td>
<td>A4 – Block 2</td>
</tr>
<tr>
<td></td>
<td>A6 – Block 3</td>
</tr>
<tr>
<td></td>
<td>A8 – Block 4</td>
</tr>
<tr>
<td></td>
<td>AA – Block 5</td>
</tr>
<tr>
<td></td>
<td>AC – Block 6</td>
</tr>
<tr>
<td></td>
<td>AE – Block 7</td>
</tr>
<tr>
<td>MAX6626 Temperature Sensor</td>
<td>90</td>
</tr>
<tr>
<td>MAX6953 LED Driver</td>
<td>B0</td>
</tr>
</tbody>
</table>

The features of these three slave devices and the software description together with the hardware design will be covered in the following sections.
2. Microchip 24AA16 E²PROM

The Microchip 24AA16 is a 16 Kbit EEPROM organized as eight blocks of $256 \times 8$-bit memory with a 2-wire interface. It also supports page-write up to 16 bytes. Figure 2 shows the block diagram.

![Figure 2 Microchip 24AA16 E²PROM Block Diagram](image)

2.1 Bus Protocol

Data transfers on the I²C bus are controlled (and framed) via two unique bus states generated by the Bus Master. These bus states are the START and STOP bit conditions. When the bus is free, both lines are HIGH.

A START condition is defined as a High-to-Low level transition on SDA while the SCL line is High. A STOP condition is defined as a Low-to-High level transition on SDA while the SCL line is High. Data must always be valid (stable) on the SDA line while SCL is high. The SDA line is only allowed to change during the low period of SCL. One data bit is transmitted per SCL clock pulse.

Following the START condition, the first 8-bit byte sent in a bus message is a 7-bit Slave address field along with a data direction or R/W bit. The data direction bit (least significant bit) controls whether the Master transmits (0 = write) or receives (1 = read) data from the addressed Slave.

The acknowledge bit is a low-level signal placed on the SDA line by the receiving device (Master or Slave) during the Master-transmitted acknowledge clock pulse (ninth High SCL clock pulse of the byte transmission). If the Slave is busy and unable to receive data or the Master needs to signal the end of data transfer, a non-acknowledge is sent (SDA High during the ninth High SCL clock pulse time).

Following the START and Slave address transmission, data is exchanged between the Master and receiver as required. Upon exchange of the final byte and its acknowledge, the Master issues the STOP condition to end bus usage.
2.1.1 Device Addressing

A control byte is the first byte received following the start condition from the master device. For the 24AA16, the first four bits of the control code are set to 1010 binary for both read and write operations. The next three bits are the block select bits (B2, B1, B0), used by the master device to select which 256-word block of memory to be accessed. These bits are in effect the three most significant bits of the word address. It should be noted that the protocol limits the size of the memory to eight blocks of 256 words; therefore the protocol can support only one 24AA16 per system. The last bit of the control byte defines the operation to be performed. When set to ‘1’, a READ operation is selected. When set to ‘0’, a WRITE operation is selected. Following the START condition, the 24AA16 monitors the SDA bus to check the device type identifier being transmitted. Upon reception of the 1010 code, the slave device outputs an acknowledge signal on the SDA line. Depending on the state of the R/W bit, the 24AA16 will select a READ or WRITE operation.

2.1.2 Bit Transfer and Data Validity

The number of data bytes transferred from the transmitter to receiver between the START and STOP conditions is determined by the Master. Each byte (eight bits) is transferred serially with the most significant bit first followed by an acknowledge bit. The state of the data line represents valid data when, after a START condition, the data line is stable for the duration of the HIGH period of the clock signal. The data on the line must be changed during the LOW period of the clock signal. There is one clock pulse per bit of data.
2.1.3 Acknowledge

Each receiving device, when addressed, is obliged to generate an acknowledge after the reception of each byte. The master device must generate an extra clock pulse which is associated with this acknowledge bit. For 24AA16, it does not generate any acknowledge bits if an internal programming cycle is in progress.

2.2 WRITE Operation

Write operations are initiated when the R/\text{W} bit of the slave address is set to ‘0’. There are two types of write operation: byte and page writes.

2.2.1 Byte Write

Byte operations allow a random EEPROM address to be written. Byte-write operations require the following transmission:

- START condition (Master)
- EEPROM Device Address with R/\text{W} = 0 (Master)
- Acknowledge Bit (EEPROM)
- Target EEPROM Word Address to be Written (Master)
- Acknowledge Bit (EEPROM)
- Data Byte to be Written (Master)
- Acknowledge bit (EEPROM)
- STOP Condition (Master)

![Figure 5 Byte Write]

2.2.2 Page Write

Page write operations allows up to 16 bytes to be written to the EEPROM. During these page writes, the EEPROM automatically increments its internal address pointer between bytes.

![Figure 6 Page Write]
2.3 READ Operation

Three types of read operations are supported: Current Address, Random, and Sequential Read. Read operations begin just like write operations, except that the R/W bit is set to 1 for the device address byte.

2.3.1 Current Address Read

In the Current Address Read mode, the data is read from the location of the most recent access. This read transmission type sequence appears as:

- START condition (Master)
- EEPROM device address with R/W = 1 (Master)
- Acknowledge bit (EEPROM)
- Data byte to be read (EEPROM bytes sent from the addressed Slave’s most recent pointed-to memory location incremented by 1)
- Non-acknowledge bit (Master)
- STOP condition (Master)

![Figure 7 Current Address Read](image)

2.3.2 Random Read

The Random Read mode is begun with a dummy byte write cycle (Master sends a START condition followed by the device address and target word address) followed by a Current Address Read mode cycle as described previously.

![Figure 8 Random Read](image)
2.3.3 Sequential Read

The Sequential Read mode is initiated with a Random Read. Instead of the Master terminating the read after a single byte exchange (with a non-acknowledge), the Master responds with a valid acknowledge after each received data byte. This acknowledge instructs the Slave EEPROM to continue the read operation and transmit out the next data byte. Sequential reads continue until terminated by the Master via issuance of a non-acknowledge on the most recent byte read followed by the STOP condition.

![Sequential Read Diagram]

**Figure 9** Sequential Read
3. \textsuperscript{i}C Temperature Sensor

The MAX6626 comprises a temperature sensor, programmable over-temperature alarm and an \textsuperscript{i}C-compatible serial interface. The temperature of the die is converted into digital values using the internal analog-to-digital converter. The converted result is stored in a temperature register, readable at any time through the serial interface. A dedicated alarm output (OT) is activated if the conversion result exceeds the value in the programmable high-temperature register. It also comes with a programmable fault queue, which sets the number of faults that must occur before the alarm activates. This prevents spurious alarms in noisy environments. The device functions as a slave and supports byte/word-read/write commands. The functional block diagram is shown in Figure 10.

![Block Diagram of Temperature Sensor](image)

**Figure 10** Block Diagram of Temperature Sensor

3.1 Addressing

Four separate addresses can be configured with the ADD pin, allowing up to four MAX6626s to be connected on the same bus. The table summarizes the different address selection. In this interface, the ADD pin is connected to GND and the address is set to 90 (hexadecimal).

<table>
<thead>
<tr>
<th>ADD Connection</th>
<th>\textsuperscript{i}C-Compatible Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>GND</td>
<td>100 1000</td>
</tr>
<tr>
<td>(V_S)</td>
<td>100 1001</td>
</tr>
<tr>
<td>SDA</td>
<td>100 1010</td>
</tr>
<tr>
<td>SCL</td>
<td>100 1011</td>
</tr>
</tbody>
</table>

**Table 2** ADD Connection
3.2 Control Registers

The operation is defined by the following registers:

a. The **Pointer** register is addressed first to determine the register to be acted on.

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Temperature</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Configuration</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>T\text{_LOW}</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>T\text{_HIGH}</td>
</tr>
</tbody>
</table>

b. The **Temperature** (TEMP) register is 12-bit, read-only and contains the latest temperature data. The register length is 16 bits with the unused bits masked to 0. The digital temperature is in °C using a two’s complement format with the LSB corresponding to 0.0625°C.

<table>
<thead>
<tr>
<th>D15</th>
<th>D14</th>
<th>D13</th>
<th>D12</th>
<th>D11</th>
<th>D10</th>
<th>D9</th>
<th>D8</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2-D0</th>
<th>MSB (Sign)</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>Bit</th>
<th>LSB</th>
<th>Unused</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 11** Reading of 2-byte Registers (TEMP, T\text{\_HIGH} and T\text{\_LOW})
c. The Configuration register is 8-bit, read/write and contains the fault queue depth, temperature alarm polarity select, interrupt mode select and shutdown control bits. Refer to Table 5 for the bit structure.

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>No. of Faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

The High-Temperature (T\textsubscript{HIGH}) register is 9-bit, read/write and contains the value that triggers the over-temperature alarm. The Low-Temperature (T\textsubscript{LOW}) register is 9-bit, read/write. It contains the value to which the temperature must fall before the over-temperature alarm is de-asserted in comparator mode. Refer to Table 6 for the bit structure of these two registers. The timing diagram for reading from and writing to are shown in Figures 11 and 14 respectively.
Table 6 \( T_{\text{HIGH}} \) and \( T_{\text{LOW}} \) Registers

<table>
<thead>
<tr>
<th>D15</th>
<th>D14</th>
<th>D13</th>
<th>D12</th>
<th>D11</th>
<th>D10</th>
<th>D9</th>
<th>D8</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSB</td>
<td>Bit 7</td>
<td>Bit 6</td>
<td>Bit 5</td>
<td>Bit 4</td>
<td>Bit 3</td>
<td>Bit 2</td>
<td>LSB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes:
1. D15: MSB is the sign bit
2. D6 to D0: Will read all zeros, cannot be written
3. LSB = 0.5°C

![Figure 14 \( T_{\text{HIGH}} \) and \( T_{\text{LOW}} \) Write](image)

3.3 Temperature Conversion

An on-chip bandgap reference produces a signal proportional to absolute temperature (PTAT), as well as the temperature-stable reference voltage necessary for the analog-to-digital conversion. The resolution of the digitized PTAT signal is 0.0625°C with the rate of conversion at 133ms. The temperature register contains the value of the most recently completed conversion.

3.4 Over-temperature Alarm

The polarity and modes (interrupt and comparator) of the dedicated over-temperature output pin (OT) are programmable through the configuration register. Fault queue depth defines the alarm activity.

- The programmable fault queue eliminates spurious alarm activity in noisy environments by setting the number of consecutive out-of-tolerance temperature readings that must occur before the OT alarm is triggered. Out-of-tolerance refer to a temperature reading above \( T_{\text{HIGH}} \) or below \( T_{\text{LOW}} \).
- In comparator mode, OT is asserted when the number of consecutive conversions exceeding the value of the \( T_{\text{HIGH}} \) register is equal to the fault queue depth. OT will be de-asserted when the number of consecutive conversions below \( T_{\text{LOW}} \) is equal to the fault queue depth. For example, \( T_{\text{HIGH}} \), \( T_{\text{LOW}} \) and fault queue depth are set to +75°C, +50°C and 4 respectively. OT will not assert until four consecutive conversions exceed +75°C. Similarly, OT will not be de-asserted until four consecutive conversions are below +50°C. Comparator mode allows autonomous clearing of an OT fault without the intervention of a master and is ideal for driving a cooling fan.
- In interrupt mode, the OT pin asserts an alarm for an under-temperature as well as an over-temperature fault, depending on certain conditions. If the fault queue is cleared at power-up, the IC looks for a \( T_{\text{HIGH}} \) fault after which it will then monitor for a \( T_{\text{LOW}} \) fault. After \( T_{\text{LOW}} \) fault, it will then monitor for a \( T_{\text{HIGH}} \) fault. This process will be repeated if OT is properly de-asserted each time. Once either fault has occurred, it remains active until de-asserted by a read of any register. The device will then monitor for a fault of the opposite type. For example, \( T_{\text{HIGH}} \), \( T_{\text{LOW}} \) and fault queue depth are set to +75°C, +50°C and 4 respectively. OT will not assert until four consecutive conversions exceed +75°C. OT will then de-assert upon reading the temperature register. OT will then assert again after four consecutive conversions below +50°C.

3.5 Shutdown

In shutdown mode, the temperature register is set to H’8000 and the ADC is turned off (reducing the device current to 1µA). Upon exiting from shutdown, the value of the temperature register is H’8000 until the completion of the first temperature conversion.
4. **I²C 4-Digit 5 × 7 Matrix LED Display Driver**

The MAX6953 is a serially interfaced display driver that can drive four digits of 5 × 7 cathode-row dot-matrix displays. It includes an ASCII 104-character font, multiplex scan circuitry, column and row drivers, static RAM to store each digit as well as font data for 24 user-definable characters. The segment current for the LEDs is set by an internal digit-by-digit digital brightness control. It also features a low-power shutdown mode, segment blinking, and a test mode that forces all LEDs to be on. Figure 15 shows the functional block diagram for the LED driver.

![Block Diagram for MAX6953](image)

**Figure 15  Block Diagram for MAX6953**

### 4.1 Serial Addressing

The MAX6953 operates as a slave that sends and receives data through an I²C-compatible 2-wire interface. The serial data (SDA) and clock (SCL) lines are used to achieve bi-directional communication between master (H8/38024) and slave (MAX6953). The master initiates all data transfers to and from the MAX6953, and also generates the SCL clock for synchronization of data transfer.

### 4.2 Start and Stop Conditions

Both SCL and SDA remain high when the interface is not busy. A master signals the beginning of a transmission with a START (S) condition by a high to low transition on SDA while SCL is high. When the master has finished communicating with the slave, it issues a STOP (P) condition by a low to high transition on SDA while SCL is high. Another bus transmission can then begin.
4.3 Bit Transfer

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable while SCL is high.

4.4 Acknowledge

The acknowledge bit is a clocked 9th bit that the recipient uses to handshake receipt of each data byte. Refer to Figure 18. Thus, each transferred byte effectively requires 9 bits. The master generates the 9th clock pulse, and the recipient pulls down SDA such that the SDA line is stable low during the high period of the acknowledge clock pulse. When the master is transmitting to the MAX6953, the acknowledge bit is generated by the MAX6953. When the MAX6953 is transmitting to the master, the master generates the acknowledge bit because the master is the recipient.
Figure 18  Acknowledge

4.5 Slave Address

The MAX6953 has a 7-bit slave address. The 8th bit following the 7-bit slave address is the R/W bit. It is low for a write command and high for a read command. The first 3 bits (A6, A5 & A4) of the MAX6953 slave address are always 101. The address input pins AD1 and ADO determine the slave address bits A3, A2, A1 and A0. These two input pins can be connected to GND, V+, SDA or SCL. Table 7 lists all the possible connections for AD1 and AD0 and the correspondingly addresses assigned to the MAX6953. Note that addresses A0 to AE (hexadecimal) have already been assigned to the EEPROM, the address B0 is allocated to the MAX6953.

Figure 19  Slave Address

<table>
<thead>
<tr>
<th>PIN</th>
<th>DEVICE ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD1</td>
<td>AD0</td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
</tr>
<tr>
<td>GND</td>
<td>V+</td>
</tr>
<tr>
<td>GND</td>
<td>SDA</td>
</tr>
<tr>
<td>GND</td>
<td>SCL</td>
</tr>
<tr>
<td>V+</td>
<td>GND</td>
</tr>
<tr>
<td>V+</td>
<td>V+</td>
</tr>
<tr>
<td>V+</td>
<td>SDA</td>
</tr>
<tr>
<td>V+</td>
<td>SCL</td>
</tr>
<tr>
<td>SDA</td>
<td>GND</td>
</tr>
<tr>
<td>SDA</td>
<td>V+</td>
</tr>
<tr>
<td>SDA</td>
<td>SDA</td>
</tr>
<tr>
<td>SDA</td>
<td>SCL</td>
</tr>
<tr>
<td>SCL</td>
<td>GND</td>
</tr>
<tr>
<td>SCL</td>
<td>V+</td>
</tr>
<tr>
<td>SCL</td>
<td>SDA</td>
</tr>
<tr>
<td>SCL</td>
<td>SCL</td>
</tr>
</tbody>
</table>
4.6 Writing Message Format

A write to the MAX6953 comprises the transmission of the slave address with the R/W set to zero followed by at least one byte of information. The first byte of information is the command byte, which determines the register to be written to by the next byte. If a STOP condition is detected after the command byte is received, then no further action other than the storage of the command byte is taken (Figure 20).

![Figure 20 Command Byte Received](image)

All bytes received after the command byte are data bytes. The first data byte goes into the internal register of the MAX6953 selected by the command byte (Figure 21).

![Figure 21 Command and Single Data Byte Received](image)

If multiple data bytes are transmitted before a STOP condition is detected, these bytes are generally stored in subsequent MAX6953 internal registers because the command byte address generally auto-increments (Refer to Table 8 and Figure 22).
4.7 Reading Message Format

The MAX6953 is read using the MAX6953’s internally stored command byte as address pointer, the same way the stored command byte is used as address pointer for a write. The pointer generally auto-increments after each data byte is read using the same rules described in Table 8. Thus, a read is initiated by performing a write (Figure 20). The master can now read n consecutive bytes from the MAX6953, with the first data byte being read from the register addressed by the initialized command byte (Figure 22).
5. Code

The functions are listed in these two C source files:

- I2C.c
  - Contains the main function
  - Performs initialization of the Serial Communication Interface (SCI) and temperature sensor
  - Tests the EEPROM, temperature sensor and the LED driver

- RW.c
  - Contains the general functions to emulate SDA and SCL

The flowchart of the main function is shown in Figure 23. The following steps are performed:

1. Initialization of SCI (2400bps, 1 stop bit, parity disabled), temperature sensor and LED driver.
2. Test EEPROM: Perform byte write, byte read, page write, read from current and sequential addresses. The test results are transmitted to the PC via SCI.
3. Read temperature, transmit to PC via SCI, and then display on Digits 1, 2 and 3.
4. Display ‘0’ to ‘9’ on Digit 0.
5. Repeat steps 2 to 4.

![Figure 23 Flowchart of Main Function](image-url)
#include "iodefine.h"
#include "i2c.h"
#include <stdio.h>
#include <machine.h>

//Device Addresses
#define EEPROM_ADDR 0xA0 //B'10100000x
#define T_SENSOR_ADDR 0x90 //B'10010000x
#define LED_DRIVER_ADDR 0xB0 //B'10110000x

//LED Driver Registers
#define DIGIT_0 0x60
#define DIGIT_1 0x61
#define DIGIT_2 0x62
#define DIGIT_3 0x63
#define DIGIT_0_1_INT_REG 0x01
#define DIGIT_2_3_INT_REG 0x02

void main(void)
{
    init_sci();
    init_temp_sensor();
init_led_driver();

PutStr("\r\nBeep Beep Beep");

while(1)
{
    test_eeprom();
    test_temp_sensor();
    test_led_matrix();
    wait(5);  //short delay
}

//----------------------------------------------------------------------
/*
test_led_matrix() – display 0 to 9 on Digit 0
*/

void test_led_matrix(void)
{
    char display_char;

    for (display_char = '0' ; display_char <= '9' ; display_char++)
    {
        LEDprint(display_char, DIGIT_0);
        wait(10);  //short delay
    }
}

//----------------------------------------------------------------------
/*
test_eeprom()
a. byte write
b. byte read
c. page write
d. current address read
e. sequential address read
*/

void test_eeprom(void)
{
    unsigned char buf[16] = {0x00, 0x11, 0x22, 0x33, 0x44, 0x55, 0x66, 0x77,
                              0x88, 0x99, 0xAA, 0xBB, 0xCC, 0xDD, 0xEE, 0xFF};

    unsigned char return_byte;
    unsigned char *ptr;

    PutStr("\r\n\nEEPROM Testing:");

    //Byte Write
    PutStr("\r\nByte Write");
if (I2cWrite(EEPROM_ADDR, buf, 1, 0x00) != OP_DONE)
    PutStr(" -> Fail!");
else
    PutStr(" -> OK");

// Need to check if write is complete
if (CheckWriteReady() == 1)
{
    // Byte Read
    PutStr("\r\nByte Read");
    return_byte = I2cRead(EEPROM_ADDR, ptr, 1, 0x00);
}

// Page Write
PutStr("\r\nPage Write");
if (I2cWrite(EEPROM_ADDR, buf, 16, 0x00) != OP_DONE)
    PutStr(" -> Fail!");
else
    PutStr(" -> OK");

// Need to check if write is complete
if (CheckWriteReady() == 1)
{
    // Current Address Read
    PutStr("\r\nCurrent Address Read");
    return_byte = I2cCurrentRead(EEPROM_ADDR, buf, 0x00);

    // Sequential Read
    PutStr("\r\nSequential Read");
    return_byte = I2cRead(EEPROM_ADDR, ptr, 16, 0x00);
}

//----------------------------------------------------------------------

/*
   test_temp_sensor()
   a. Get temperature reading
   b. Convert from binary to floating point
   c. Transmit temperature to PC via SCI
   d. Display temperature on Digits 1, 2 and 3
*/

void test_temp_sensor(void)
{
    unsigned char return_byte;
    unsigned char tens, ones, tenths;
    unsigned int   return_code;
    float          degree;

    // read from temperature sensor
return_code = I2cRead_T_Sensor(T_SENSOR_ADDR, 0x00);

if (return_code == 0x8000)
    PutStr("SHUT DOWN!");
else
    PutStr("\r\n\nTemperature : ");

degree = ConvertBinary2Temp(return_code);

//For example, temperature = 37.1 degree
//tens = 3, ones = 7 & tenths = 1
tens = 0;
ones = 0;
tenths = 0;

while (degree >= 10)
{
    tens++;
    degree -= 10;
}

while (degree >= 1)
{
    ones++;
    degree -= 1;
}

while (degree >= 0.1)
{
    tenths++;
    degree -= 0.1;
}

//Transmit to PC via SCI
char_put(tens + 0x30);
char_put(ones + 0x30);
char_put(0x2E);   //decimal point
char_put(tenths + 0x30);

//Display on dot-matrix LED
LEDprint(tens + 0x30, DIGIT_1);
LEDprint(ones + 0x30, DIGIT_2);
LEDprint(tenths + 0x30, DIGIT_3);

/*============================================================================

   init_temp_sensor()

*/

void init_led_driver(void)
{
    unsigned char return_byte;
//Configure MAX6953 driver: wake from shutdown mode
SendStartBit();
SendByte((LED_DRIVER_ADDR) & 0xfe);
SendByte(0x04);  //configuration register
SendByte(0x01);  //select normal operation as power-on default -> shutdown
SendStopBit();

//Set the intensity register for digits 0 & 1 to 6/16 duty cycle
//Set the intensity register for digits 2 & 3 to 6/16 duty cycle
//Write 0x66 to both 0x01 and 0x02 reg of MAX6953EPL
SendStartBit();
SendByte((LED_DRIVER_ADDR) & 0xfe);  //Send Slave Address byte
SendByte(DIGIT_0_1_INT_REG);  //Send COMMAND byte
SendByte(0x66);     //Send data byte 00-min, FF-max
SendStopBit();      //Send stop bit
SendStartBit();
SendByte((LED_DRIVER_ADDR) & 0xfe);  //Send Slave Address byte
SendByte(DIGIT_2_3_INT_REG);  //Send COMMAND byte
SendByte(0x66);     //Send data byte 00-min, FF-max
SendStopBit();      //Send stop bit

/*==========================================================================
*/
/*
  init_temp_sensor()
*/

void init_temp_sensor(void)
{
  unsigned char return_byte;

  SendStartBit();
  SendByte((T_SENSOR_ADDR) & 0xfe);  //Send slave address byte
  SendByte(0x01);  //Configuration Register of sensor
  SendByte(0x00);  //Wake up device
  SendStopBit();   //Send stop bit
  SendStartBit();
  SendByte((T_SENSOR_ADDR) & 0xfe);  //Send slave address byte
  SendByte(0x01);  //Configuration Register of sensor
  SendStopBit();

  SendStartBit();
  SendByte((T_SENSOR_ADDR) | 0x01);  //Read from Configuration Register
  return_byte = GetByte();
  SendStopBit();

  //THIGH = 80 degrees
  //TLOW  = 0 degrees
  SendStartBit();
  SendByte((T_SENSOR_ADDR) & 0xfe);  //Send Slave Address byte
  SendByte(0x03);  //Set Max Temperature of Sensor
  SendByte(0x50);   //msbByte
SendByte(0x00);  //lsbByte
SendStopBit();  //Send stop bit

SendStartBit();
SendByte((T_SENSOR_ADDR) & 0xfe);  //Send slave address byte
SendByte(0x02);  //Set Min Temperature of Sensor
SendByte(0x00);  //msbByte
SendByte(0x00);  //lsbByte
SendStopBit();  //Send stop bit

//------------------------------------------------------------------------------

This routine is written for MAXIM 12-bit Temperature Sensors. MAX6626 is a 12-bit i2c compatible sensors.

input:
unsigned char slave_addr - refer to the address preset
unsigned char ptr_reg - refer to the pointer register
  0x00 temperature
  0x01 configuration
  0x02 high-temperature
  0x03 low-temperature

return:
  unsigned int - current temperature in 16bits

//------------------------------------------------------------------------------

unsigned int I2CRead_T_Sensor(unsigned char slave_addr, unsigned char ptr_reg)
{
  unsigned int theWORD;
  unsigned char msbBYTE, lsbBYTE;

  if (CheckBusState() != TRUE)
    return(BUS_BUSY);

  SendStartBit();
  //Send slave address with write command
  if (SendByte((slave_addr) & 0xfe) != LOW)    return(NO_RESPONSE);

  //Send Pointer byte
  if (SendByte(ptr_reg) != LOW)
    return(NO_RESPONSE);

  SendStopBit();    //Send STOP bit
  SendStartBit();

  //Send slave address with read command
  if (SendByte((slave_addr) | 0x01) != LOW)
    return(NO_RESPONSE);

  theWORD = SendByte();
  SendByte();
msbBYTE = GetByte();

SendBit(LOW);       //Ack it low!

lsbBYTE = GetByte();

SendStopBit();      //Send STOP bit

theWORD = (unsigned int)msbBYTE << 8;
theWORD = theWORD + lsbBYTE;

return(theWORD);

}  

//****************************************************************************

/*
ConvertBinary2Temp() Converts temperature from binary to floating point
*/

float ConvertBinary2Temp(unsigned int temp)
{
    float degree;
    float scaleMX;
    int  temp1;

    scaleMX = 0.0625;

    temp1 = temp & 0x7FFF;  //throw away signed bit
    temp1 = temp1>>4;   //get rid of last 4 bits(lsb)

    degree = (float)temp1 * scaleMX;

    return(degree);
}

//****************************************************************************

/*
   LEDprint(): Display on the matrix LED.
 */

void LEDprint(char character, unsigned char digit_position)
{
    unsigned char  error_code;

    error_code = I2cMatrixLEDdriver(LED_DRIVER_ADDR, digit_position, character);
}

//****************************************************************************

/*
   This routine is used for MAXIM Matrix LED Display Driver.
 */
MAX6953 is a 2-wire I2C interface driver.

slave_addr is the address preset for MAX6953.

command_byte refer to the command instruction to be given to MAX6953.

data_byte refer to the 8-bit data

unsigned char I2cMatrixLEDdriver(unsigned char slave_addr, unsigned char command_byte, unsigned char data_byte)
{
    /*
    Command Address:

    StartBit [S] -> Slave Address (7bit + 1 R/W bit) -> ACK (MAX6953) ->
    COMMAND Byte -> ACK (MAX6953) -> DATA byte -> ACK (MAX6953) -> StopBit [P]

    Refer to MAX6953 data sheet for command and data instruction
    */

    //Check if I2C bus is busy
    if (CheckBusState() != TRUE)
        return(BUS_BUSY);

    SendStartBit();    //Send start bit
    //Send slave address and write command
    if (SendByte((slave_addr) & 0xfe) != LOW)
        return(NO_RESPONSE);
    if (SendByte(command_byte) != LOW) //Send COMMAND byte
        return(NO_RESPONSE);
    if (SendByte(data_byte) != LOW)  //Send DATA byte
        return(NO_RESPONSE);

    SendStopBit();      //Send stop bit
}

//----------------------------------------------------------------------

/*
init_sci() : Sets up the Serial Communication Interface for debugging
*/

void init_sci(void)
{
    //SCR3 : |TIE|RIE|TE|RE|MPIE|TEIE|CKE1|CKE0|
    //TIE : Transmit interrupt enable
    //RIE : Receive interrupt enable
    //TE  : Transmit enable
    //RE  : Receive enable
    //MPIE : Multiprocessor interrupt enable
    //TEIE : Transmit end interrupt enable
// CKE1 : Clock enable 1
// CKE0 : Clock enable 0

// CKE1 = CKE0 = 0
// asynchronous mode, internal clock source, SCK32 functions as I/O port
P_SCI3.SCR3.BYTE &= 0x00; // clear TE & RE

// SMR : |COM|CHR|PE|PM|STOP|MP|CKS1|CKS0| : |0|0|0|0|0|0|0|0|
// COM : Communication Mode : 0 : asynchronous mode
// CHR : Character Length : 0 : character length = 8 bits
// PE : Parity Enable : 0 : parity bit addition and checking disabled
// PM : Parity Mode : 0 : even parity (no effect since no parity)
// STOP : Stop Bit Length : 0 : 1 stop bit
// MP : Multiprocessor Mode : 0 : multiprocessor comm function disabled
// |CKS1|CKS0| : Clock Select : |0|0| : clock source for baud rate gen = clk
P_SCI3.SMR.BYTE = 0x00;

// For clk = 10MHz, bit rate = 2400 bps, n = 0, N = 64
P_SCI3.BRR = 64;

// minimum of 1-bit delay = 417ns
nop();
nop();
nop();

// SPCR : |---|---|SPC32|---|SCINV3|SCINV2|---|---| : |1|1|1|0|0|0|0|0|
// SPC32 = 1 : P42 functions as TXD32 output pin
// need to set TE bit in SCR3 after setting this bit to 1
// SCINV3 = 0 : TXD32 output data is not inverted
// SCINV2 = 0 : RXD32 input data is not inverted
// Bits 7 and 6 are reserved and always read as 1
// Bits 4, 1 and 0 are reserved and only 0 can be written to these bits
P_SCI3.SPCR.BYTE = 0xE0;

P_SCI3.SCR3.BYTE |= 0x30; // Set TE & RE
}

//------------------------------------------------------------------------------

/*
 void char_put(char OutputChar)              // Serial Port
 {
  |SSR : |TDRE|RDRF|OER|FER|PER|TEND|MPBR|MPBT|
  |TDRE : transmit data register empty
  |RDRF : receive data register full
  |OER : overrun error
  |FER : framing error
  |PER : parity error
  |TEND : transmit end
  |MPBR : Multiprocessor bit receive
  |MPBT : Multiprocessor bit transfer
 */

void char_put(char OutputChar)              // Serial Port
{
  // SSR : |TDRE|RDRF|OER|FER|PER|TEND|MPBR|MPBT|
  // TDRE : transmit data register empty
  // RDRF : receive data register full
  // OER : overrun error
  // FER : framing error
  // PER : parity error
  // TEND : transmit end
  // MPBR : Multiprocessor bit receive
  // MPBT : Multiprocessor bit transfer
}
while ((P_SCI3.SSR.BIT.TDRE) == 0); //Wait for TDRE = 1
P_SCI3.TDR = OutputChar;
}

//----------------------------------------------------------------------

/*
  PutStr() : Transmits a string of characters to the PC for debugging
  purposes.
*/
void PutStr(char *str)
{
    while (*str != 0)
    {
        char_put(*str);
        str++;
    }
}

//----------------------------------------------------------------------

/*
  wait(): Generates a software delay.
*/
void wait(unsigned int time)
{
    unsigned int i, j;

    for (i = 0 ; i < time ; i++)
    {
        for (j = 0 ; j < 3500 ; j++)
        {

        }
    }
}

//----------------------------------------------------------------------


#include "i2c.h"
#include "iodefine.h"

unsigned char SclIn(void)
{
    SCL_IO_REG &= SCL_IO_RESET_BIT; //Set to Input
    if (SCL_DATA_REG & SCL_DATA_SET_BIT) //Check pin status
    {
        return(HIGH);
    }
    else
    {
        return(LOW);
    }
}

unsigned char SdaIn(void)
{
    SDA_IO_REG &= SDA_IO_RESET_BIT; //Set to Input
    if (SDA_DATA_REG & SDA_DATA_SET_BIT) //Check pin status
    {
        return(HIGH);
    }
    else
    {
        return(LOW);
    }
}
return(LOW);
}

//-----------------------------------------------------------------------
/*
SclOut()
Defines the SCL pin as an output pin and sets it to the level
determined by the parameter.
*/

void SclOut(unsigned char status)
{
    if (status == LOW)
    {
        SCL_DATA_REG = 0;                //Drive Port LOW
    }
    else
    {
        SCL_DATA_REG = 1;                //Drive Port High
    }
    SCL_IO_REG |= SCL_IO_SET_BIT;  //Set to output
}

//-----------------------------------------------------------------------
/*
SdaOut()
Defines the SDA as an output pin and sets it to the level determined by the
parameter.
*/

void SdaOut(unsigned char status)
{
    if (status == LOW)
    {
        SDA_DATA_REG = 0;                //Drive Port LOW
    }
    else
    {
        SDA_DATA_REG = 1;             //Drive Port High
    }
    SDA_IO_REG |= SDA_IO_SET_BIT;  //Set to output
}

//-----------------------------------------------------------------------
/*
Delay()
Provide an internal minimum delay time to bridge the undefined
region of a falling edge of SCL to avoid unintended generation
void Delay(void)
{
    unsigned char i = 0;
    while (i < 20)
    {
        i++;
    }
}

void Delay2x(void)
{
    Delay();
    Delay();
}

unsigned char CheckBusState(void)
{
    if ((SclIn() == HIGH) && (SdaIn() == HIGH))
    {
        return(TRUE);
    }
    else
    {
        return(FALSE);
    }
}

void SendStartBit(void)
{
    Delay();
    SdaOut(LOW);
    Delay2x();
Delay2x();
Delay2x();
Delay2x();
SclOut(LOW);
Delay();
}

().'/**************************************************************************/

\* SendBit(): Send out data in bit format \*
\*/

void SendBit(unsigned char data_byte)
{
    SclOut(LOW);
    Delay();
    if (data_byte != 0)
    {
        SdaOut(HIGH);
    }
    else
    {
        SdaOut(LOW);
    }
    Delay();
    SclOut(HIGH);
    while (SclIn() != HIGH) {}  //wait for slow device to release clock
    Delay2x();
}

/**********************************************************************************/

\* GetBit(): Receive data input in bit format \*
\*/

unsigned char GetBit(void)
{
    unsigned char temp;
    SclOut(LOW);
    temp = SdaIn();
    Delay2x();
    SclOut(HIGH);
    while (SclIn() != HIGH) {}  //wait for slow device to release clock
    Delay();
    temp = SdaIn();
Delay();
return(temp);
}

//-------------------------------

/*
* GetAck():
* Getting ACK is similar to GetBit, but this is critical operation since
* master must pull SDA high before it finds out whether there is a ACK
* (SDA is low) or not.
*/

unsigned char GetAck(void)
{
    unsigned char temp;

    SclOut(LOW);
    Delay();
    SdaOut(HIGH);
    temp = SdaIn();
    Delay();
    SclOut(HIGH);
    while (SclIn() != HIGH) {}  //wait for slow device to release clock
    Delay();
    temp = SdaIn();
    Delay();
    return(temp);
}

//-------------------------------

/*
* SendByte(): Send out a byte starting with most significant bit (MSB) first.
*/

unsigned char SendByte(unsigned char data_byte)
{
    unsigned char i;
    unsigned char mask;

    mask = 0x80;  //send out MSB first

    for (i = 0 ; i < 8 ; i++)
    {
        SendBit(data_byte & mask);
        mask >>= 1;
    }

    return(GetAck());
}

//-------------------------------
/* GetByte(): Get a byte of data starting with most significant bit (MSB) */

unsigned char GetByte(void)
{
    unsigned char  temp1, temp2;
    unsigned char  i,mask;

    mask = 0x80;
    temp2 = 0;

    for (i = 0; i < 8 ; i++)
    {
        temp1 = GetBit() * mask;
        temp2 += temp1;
        mask >>= 1;
    }
    return(temp2);
}

//-----------------------------------------------------------------------
/*
 * SendStopBit(): Send a STOP condition to terminate the operation *
 */

void SendStopBit(void)
{
    SclOut(LOW);
    Delay();
    SdaOut(LOW);
    Delay();
    SclOut(HIGH);
    Delay2x();
    SdaOut(HIGH);
}

//-----------------------------------------------------------------------
/*
 * I2cWrite()
 
 a. Byte Write
 1. Start Bit
 2. Control Byte
 3. Ack
 4. Word Address
 5. Ack
 6. Data
 7. Ack
 8. Stop Bit
 */
b. Page Write
   1. Start Bit
   2. Control Byte
   3. Ack
   4. Word Address
   5. Ack
   6. Data(n)
   7. Ack
   8. Data(n + 1)
   9. Ack
   ...
   10. Data(n + 15)
   11. Ack
   12. Stop Bit

,unsigned char I2cWrite(unsigned char slave_addr, unsigned char *buf_ptr,
                           unsigned char length, unsigned char word_addr)
{
    unsigned int    i;
    if (CheckBusState() != TRUE)
    {
        PutStr(" -> BUS_BUSY!");
        return(BUS_BUSY);
    }
    SendStartBit();

    //Send address and write command
    if (SendByte((slave_addr) & 0xfe) != LOW)
    {
        PutStr(" -> NO_RESPONSE-1");
        return(NO_RESPONSE);
    }

    //Send word address
    if (SendByte(word_addr) != LOW)
    {
        PutStr(" -> NO_RESPONSE-2");
        return(NO_RESPONSE);
    }

    for (i = 0 ; i < length ; i++)
    {
        //Write data
        if (SendByte(*buf_ptr++) != LOW)
        {
            PutStr(" -> ERR_RESPONSE");
            return(ERR_RESPONSE);
        }
    }
    SendStopBit();
return(OP_DONE);
}

//-----------------------------------------------------------------------
unsigned char I2cRead(unsigned char slave_addr, unsigned char *buf_ptr, unsigned char length, unsigned char word_addr)
{
    unsigned char i = 0, j = 0;
    unsigned char ref_data[16] = {0x00, 0x11, 0x22, 0x33, 0x44, 0x55, 0x66, 0x77, 0x88, 0x99, 0xAA, 0xBB, 0xCC, 0xDD, 0xEE, 0xFF};
    unsigned char DataBuffer[256];
    unsigned char error = 0;
    if (CheckBusState() != TRUE)
    {
        PutStr(" -> BUS_BUSY");
        return(BUS_BUSY);
    }
    SendStartBit();

    //Send dummy address and write command
    if (SendByte((slave_addr) & 0xfe) != LOW)
    {
        PutStr(" -> NO_RESPONSE-1!");
        return(NO_RESPONSE);
    }

    //Send high word address
    if (SendByte(word_addr) != LOW)
    {
        PutStr(" -> NO_RESPONSE-2!");
        return(NO_RESPONSE);
    }

    SdaOut(HIGH);     //Pull-up SDA line
    SendBit(HIGH);
    SendStartBit();

    //Send address and read command
    if (SendByte((slave_addr) | 0x01) != LOW)
    {
        PutStr(" -> NO_RESPONSE-3!");
        return(NO_RESPONSE);
    }

    for (i = 0 ; i < length - 1 ; i++)
    {
        DataBuffer[i] = GetByte(); //read data
        SendBit(LOW);               //ack it low
    }
//Get last data byte and ack high
DataBuffer[length - 1] = GetByte();
SendBit(HIGH);
SendStopBit();

for (i = 0 ; i < length ; i++)
{
    if (DataBuffer[i] != ref_data[word_addr + i])
    {
        error++;
    }
}

if (error)
{
    PutStr(" -> Incorrect Data!");
}
else
{
    PutStr(" -> OK");
}

return(OP_DONE);
}

//-----------------------------------------------------------------------
unsigned char I2cCurrentRead(unsigned char slave_addr,
unsigned char *buf_ptr,
unsigned char word_addr)
{
    unsigned char ref_data[16] = {0x00, 0x11, 0x22, 0x33, 0x44, 0x55, 0x66,
    0x77, 0x88, 0x99, 0xAA, 0xBB, 0xCC, 0xDD,
    0xEE, 0xFF};

    SendStartBit();

    //Send address and read command
    if (SendByte((slave_addr) | 0x01) != LOW)
    {
        PutStr(" -> NO_RESPONSE!");
        return(NO_RESPONSE);
    }

    *buf_ptr = GetByte();  //get data and ack high
    SendBit(HIGH);
    SendStopBit();

    if (*buf_ptr != ref_data[word_addr])
    {
        PutStr(" -> Incorrect Data!");
    }
}  
else  
{  
    PutStr(" -> OK");  
}  

return(OP_DONE);  
}  

//------------------------------------------------------------------------------------------------------  

/*  
Since Microchip devices such as 24AA16 will not acknowledge during the internal write cycle, this can be used to determined when this cycle is complete so that the master can proceed with next operation.  

Acknowledge Polling  
a. Send write command  
b. Send stop condition to initiate write cycle  
c. Send start bit  
d. Send control byte with r/w_n = 0  
e. If device acknowledge, goto f. Else go to c  
f. Ready for next operation  

Note that (c) to (e) - internal write cycle  */  
char CheckWriteReady(void)  
{  
    unsigned int   i = 0;  
    
    while (i < 4)  
    {  
        SendStartBit();  
        
        if ((SendByte((0xa0) | 0x00) == LOW)  
        {  
            SendStopBit();  
            return (1);  
        }  
        
        SendStopBit();  
        i++;  
    }  
    
    return (0);  
}  

//------------------------------------------------------------------------------------------------------
6. Hardware Design
7. References

6. *Application Note on Serial Peripheral Interface (SPI™) & Inter-IC (I²C™)*, 2003, Renesas Technology Corporation.

Note: I²C is a registered trademark of Philips.
## Revision Record

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