CONFIDENTIAL

SET A

UNIVERSITI KUALA LUMPUR
Malaysia France Institute

FINAL EXAMINATION
JANUARY 2014 SESSION

SUBJECT CODE	:	**FSB33404**
SUBJECT TITLE	:	**EMBEDDED SYSTEM TECHNOLOGY**
LEVEL	:	**BACHELOR**
TIME / DURATION	:	**(3 HOURS)**
DATE	:	

INSTRUCTIONS TO CANDIDATES

1. **Please read the instructions given in the question paper CAREFULLY.**
2. **This question paper is printed on both sides of the paper.**
3. **Please write your answers on the answer booklet provided.**
4. **Answer should be written in blue or black ink except for sketching, graphic and illustration.**
5. **This question paper consists of ONE (1) section only.**
6. **Answer all questions in English.**
7. **Data sheet are attached in Appendix.**

THERE ARE 7 PAGES OF QUESTIONS AND 10 APPENDIXES, EXCLUDING THIS PAGE.

Total: 100 marks

INSTRUCTION: Answer FOUR (4) from FIVE (5) questions only.
Please use the answer booklet provided.

Question 1

(a) With an exemplary industrial application, describe the system in term of embedded system.

(4 marks)

(b) The following statements described the Embedded Systems characteristics. Briefly discuss.

i. Reactive systems

(3 marks)

ii. Dedicated towards a certain application

(3 marks)

iii. Required to meet real-time constraints

(3 marks)

(c) Define and discuss the following aspects of Embedded Systems dependability.

i. Availability

(3 marks)

ii. Safety

(3 marks)

(d) Define and discuss the Embedded Systems efficiency in terms of:

i. Run-time efficiency

(3 marks)

ii. Code size

(3 marks)

Question 2

(a) Consider a Telegraph System that allows you to connect a printer that has only a high-speed serial port to a network. The functions of telegraph are as follows:

- Sort out the chaos on the network and provide a clean data stream to the printer.
- Feed the printer at one print job at a time and somehow hold off the other entire computer. There might be many computers on the network, all of which might want to print on the same time.
- The response is quite rapid to certain events. There are various kinds of network frames to which the Telegraph System must send a response within 200 microseconds.

Describe on how the "Function Queue Scheduling" architecture may handle the system above.

(8 marks)

(b) Define and describe the software architecture that is being used in the following example.

```
!!Queue of function pointers
void interrupt vHandlerDeviceA(void)
{
      !!Take care of I/O Device A
      !!Put function_A on queue of function pointers
}

void interrupt vHandlerDeviceB(void)
{
      !!Take care of I/O Device B
      !!Put function_B on queue of function pointers
}

void main(void)
{
      while (TRUE)
      {
            While(!!Queue of function pointers is empty);
            !!Call first function on queue
      }
}
void function_A(void)
{
      !!Handle action required by device A
}
void function_B(void)
{
      !!Handle action required by device B
}
```

(8 marks)

(c) The bar-code scanner is essentially a device that gets the data from the laser, which reads the bar codes and sends the data out on the radio. In this system, as in the bridge, the only real response requirements are to service the hardware quick enough.

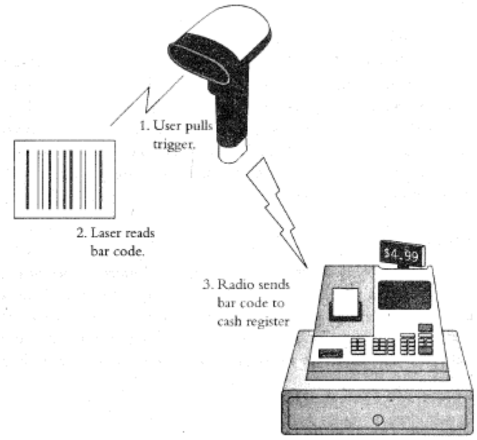


Figure 1: Cordless Bar-Code Scanner

i. State the appropriate software architecture that might be used for a system as such.

(1 mark)

ii. Justify your answer.

(8 marks)

Question 3

(a) Figure 2 shows a microcontroller based system. Sketch and explain three typical interfacing methods between MCU1 and MCU2 to expand the system I/Os (input and output).

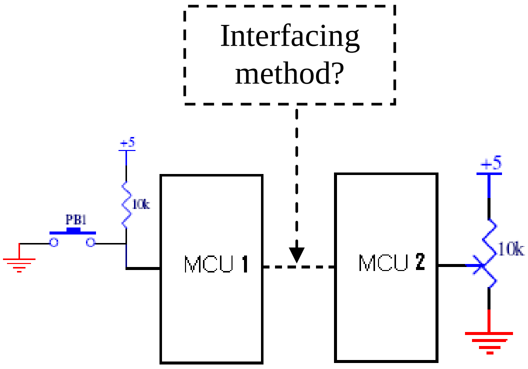


Figure 2: Microcontroller Interfacing

(15 marks)

(b) By referring to the interfacing design shown in Figure 3, answer the following questions:

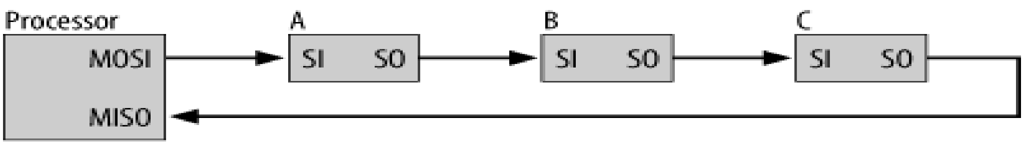


Figure 3: Interfacing Design

i. Identify type of bus and configuration used.

(4 marks)

ii. Explain the process if the Master wishes to read the data from Slave A.

(6 marks)

Question 4

(a) Given is a common block diagram to capture signal from the analog world. Explain briefly the function of transducer in term of analog sensor.

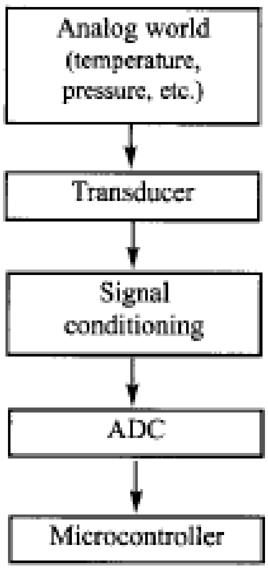


Figure 4: Capturing Analog Signal Process

(5 marks)

(b) Figure 5 shows the analog temperature display system. The system design is based on following points:

- The LM34 is connected to channel 2 (ADC2 pin);
- Display the binary temperature value on LEDs (High byte: Port C and Low byte: Port D);
- Choose the left-justified data option.

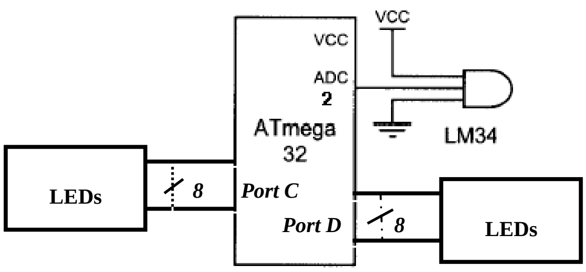


Figure 5: LM35 and LED display connection to AVR

Note: *LM34 datasheet, WINAVR C programming reference and register description are attached in Appendix 1, 2 and 3.*

Complete the program and comment (i-viii) below:

```
#include <avr\io.h>
#include <avr\interrupt.h>

..................................(i) //Interrupt Service Routine Function
{
      ..................................(ii)  //Give the low byte to PORTD
      PORTC = ADCH;
      ADCSRA |= (1<<ADSC);   //start conversion
}

int main(void)
{
      DDRC = 0XFF
      DDRD = 0XFF;
      DDRA = 0;      // ................................................(iii)
      sei();         // ................................................(iv)
      .......................(v)  //ADC enable, ADC Prescaler clock/128
      .......................(vi)//Internal 2.56Vref,ADC2 single-ended,input left-justified data
      .......................(vii)  //Start conversion
      while (1);     // ..................................(viii)
      return 0;
}
```

(10 marks)

(c) Compute the values of ADCH and ADCL for 50 degree temperature.

(10 marks)

Question 5

Thermocouples are used extensively in the steel and iron industries to monitor temperatures and chemistry throughout the steel making process. A signal conditioning chip is needed to convert the analog value to digital. Given the datasheet of MAX6675 (refer *Appendix 4*). All questions below are based on the information given in the datasheet.

(a) What type of peripheral interfacing method used between the microcontroller and the K-Thermocouple to Digital Converter chip?

(2 marks)

(b) Draw a general block diagram, complete with pin assignment to show the connection between the Thermocouple sensor - MAX6675 Chip – Microcontroller.

(5 marks)

(c) We are designing a temperature monitoring system for two boilers. Thus, two thermocouple sensors are needed for the stated task and eight LEDs is used to display the temperature value in binary form. Modify the block diagram in Question 5(b) to fulfill the system design.

(5 marks)

(d) Write a *pseudo-code* to capture the temperature values from two thermo-couple sensors using plain Round Robin architecture. You are advised to use for loop statement which allows the code to be iteratively capturing digital values from the sensors.

(8 marks)

(e) Each task in plain Round Robin architecture has specific time for execution. System above will read the converted temperature value from the MAX6675 and display the digital value on LEDs. What will be the maximum time (second) needed for the MAX6675 to convert the analog value to digital and explains why this method programming design is sufficient to the system.

(5 marks)

END OF QUESTION

APPENDIX 1

LM34 Datasheet

National Semiconductor

November 2000

LM34
Precision Fahrenheit Temperature Sensors

General Description

The LM34 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Fahrenheit temperature. The LM34 thus has an advantage over linear temperature sensors calibrated in degrees Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Fahrenheit scaling. The LM34 does not require any external calibration or trimming to provide typical accuracies of ±½°F at room temperature and ±1½°F over a full −50 to +300°F temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM34's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies or with plus and minus supplies. As it draws only 75 µA from its supply, it has very low self-heating, less than 0.2°F in still air. The LM34 is rated to operate over a −50° to +300°F temperature range, while the LM34C is rated for a −40° to +230°F range (0°F with improved accuracy). The LM34 series is available packaged in hermetic TO-46 transistor packages, while the LM34C, LM34CA and LM34D are also available in the plastic TO-92 transistor package. The LM34D is also available in an 8-lead surface mount small outline package. The LM34 is a complement to the LM35 (Centigrade) temperature sensor.

Features

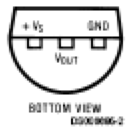
- Calibrated directly in degrees Fahrenheit
- Linear +10.0 mV/°F scale factor
- 1.0°F accuracy guaranteed (at +77°F)
- Rated for full −50° to +300°F range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 5 to 30 volts
- Less than 90 µA current drain
- Low self-heating, 0.18°F in still air
- Nonlinearity only ±0.5°F typical
- Low-impedance output, 0.4Ω for 1 mA load

Connection Diagrams

TO-46
Metal Can Package
(Note 1)

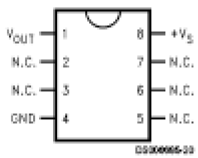
Order Numbers LM34H, LM34AH, LM34CH, LM34CAH or LM34DH
See NS Package Number H03H

TO-92
Plastic Package



Order Number LM34CZ, LM34CAZ or LM34DZ
See NS Package Number Z03A

SO-8
Small Outline Molded Package



N.C. = No Connection

Top View
Order Number LM34DM
See NS Package Number M08A

Note 1: Case is connected to negative pin (GND).

 www.national.com

Absolute Maximum Ratings (Note 11)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temperature,	
TO-46 Package	−76°F to +356°F
TO-92 Package	−76°F to +300°F
SO-8 Package	−65°C to +150°C
ESD Susceptibility (Note 12)	800V
Lead Temp.	
TO-46 Package	
(Soldering, 10 seconds)	+300°C
TO-92 Package	
(Soldering, 10 seconds)	+260°C
SO Package (Note 13)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
Specified Operating Temp. Range (Note 3)	
	T_{MIN} to T_{MAX}
LM34, LM34A	−50°F to +300°F
LM34C, LM34CA	−40°F to +230°F
LM34D	+32°F to +212°F

DC Electrical Characteristics (Notes 2, 7)

Parameter	Conditions	LM34A			LM34CA			Units (Max)
		Typical	Tested Limit (Note 5)	Design Limit (Note 6)	Typical	Tested Limit (Note 5)	Design Limit (Note 6)	
Accuracy (Note 8)	$T_A = +77°F$	±0.4	±1.0		±0.4	±1.0		°F
	$T_A = 0°F$	±0.6			±0.6		±2.0	°F
	$T_A = T_{MAX}$	±0.8	±2.0		±0.8	±2.0		°F
	$T_A = T_{MIN}$	±0.8	±2.0		±0.8		±3.0	°F
Nonlinearity (Note 9)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.35**		**±0.7**	**±0.30**		**±0.6**	°F
Sensor Gain	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9,**		**+10.0**		**+9.9,**	mV/°F, min
(Average Slope)			**+10.1**				**+10.1**	mV/°F, max
Load Regulation	$T_A = +77°F$	±0.4	±1.0		±0.4	±1.0		mV/mA
(Note 4)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
	$0 \le I_L \le 1$ mA							
Line Regulation	$T_A = +77°F$	±0.01	±0.05		±0.01	±0.05		mV/V
(Note 4)	$5V \le V_S \le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current	$V_S = +5V$, +77°F	75	90		75	90		µA
(Note 10)	$V_S = +5V$	**131**		**160**	**116**		**139**	µA
	$V_S = +30V$, +77°F	76	92		76	92		µA
	$V_S = +30V$	**132**		**163**	**117**		**142**	µA
Change of Quiescent	$4V \le V_S \le 30V$, +77°F	+0.5	2.0		0.5	2.0		µA
Current (Note 4)	$5V \le V_S \le 30V$	**+1.0**		**3.0**	**1.0**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.30**		**+0.5**	**+0.30**		**+0.5**	µA/°F
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L = 0$	+3.0		+5.0	+3.0		+5.0	°F
Long-Term Stability	$T_J = T_{MAX}$ for 1000 hours	±0.16			±0.16			°F

Note 2: Unless otherwise noted, these specifications apply: −50°F ≤ T_J ≤ + 300°F for the LM34 and LM34A; −40°F ≤ T_J ≤ +230°F for the LM34C and LM34CA; and +32°F ≤ T_J ≤ + 212°F for the LM34D. V_S = +5 Vdc and I_{LOAD} = 50 µA in the circuit of *Figure 2*; +6 Vdc for LM34 and LM34A for 230°F ≤ T_J ≤ 300°F. These specifications also apply from +5°F to T_{MAX} in the circuit of *Figure 1*.

Note 3: Thermal resistance of the TO-46 package is 720°F/W junction to ambient and 43°F/W junction to case. Thermal resistance of the TO-92 package is 324°F/W junction to ambient. Thermal resistance of the small outline molded package is 400°F/W junction to ambient. For additional thermal resistance information see table in the Typical Applications section.

Note 4: Regulation is measured at constant junction temperature using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 5: Tested limits are guaranteed and 100% tested in production.

Note 6: Design limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 7: Specification in **BOLDFACE TYPE** apply over the full rated temperature range.

APPENDIX 2
WINAVR C Programming

Code	Comment
`DDRB = 0xff;`	All port B pins as output
`PORTB = 0xff;`	All port B pins set to “1”
`DDRB |= 1<<DDB2;`	Set port B pin 2 as output
`DDRB &= ~(1<<DDB2);`	Set port B pin 2 as input
`PORTB |= _BV(PB2);` or `PORTB |= 1<<2;` or `PORTB |= 1<<PINB2;`	Set port B pin 2 to “1”
`PORTB &= ~_BV(PB2);` or `PORTB &= ~(1<<2);` or `PORTB &= ~1<<PINB2;`	Set port B pin 2 to “0”

`if (PIND & (1<<PIND3))`
`{`
`...`
`}`
	Check if port D pin 3 equal to “1”

`if (!(PIND & (1<<PIND3)))`
`{`
`...`
`}`
	Check if port D pin 3 equal to “0”

APPENDIX 3

Analog to Digital Converter: Register Description

ADC Multiplexer Selection Register – ADMUX

Bit	7	6	5	4	3	2	1	0	
	REFS1	REFS0	ADLAR	MUX4	MUX3	MUX2	MUX1	MUX0	ADMUX
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7:6 – REFS1:0: Reference Selection Bits**

These bits select the voltage reference for the ADC, as shown in Table 89. If these bits are changed during a conversion, the change will not go in effect until this conversion is complete (ADIF in ADCSRA is set). The internal voltage reference options may not be used if an external reference voltage is being applied to the AREF pin.

Table 89. Voltage Reference Selections for ADC

REFS1	REFS0	Voltage Reference Selection
0	0	AREF, Internal Vref turned off
0	1	AVCC with external capacitor at AREF pin
1	0	Reserved
1	1	Internal 1.1V Voltage Reference with external capacitor at AREF pin

- **Bit 5 – ADLAR: ADC Left Adjust Result**

The ADLAR bit affects the presentation of the ADC conversion result in the ADC Data Register. Write one to ADLAR to left adjust the result. Otherwise, the result is right adjusted. Changing the ADLAR bit will affect the ADC Data Register immediately, regardless of any ongoing conversions. For a complete description of this bit, see "The ADC Data Register – ADCL and ADCH" on page 208.

- **Bits 4:0 – MUX4:0: Analog Channel Selection Bits**

The value of these bits selects which combination of analog inputs are connected to the ADC. See Table 90 for details. If these bits are changed during a conversion, the change will not go in effect until this conversion is complete (ADIF in ADCSRA is set).

Table 90. Input Channel Selections

<table>
<tr><th>MUX4..0</th><th>Single Ended Input</th><th>Positive Differential Input</th><th>Negative Differential Input</th></tr>
<tr><td>00000</td><td>ADC0</td><td rowspan="16" colspan="2">N/A</td></tr>
<tr><td>00001</td><td>ADC1</td></tr>
<tr><td>00010</td><td>ADC2</td></tr>
<tr><td>00011</td><td>ADC3</td></tr>
<tr><td>00100</td><td>ADC4</td></tr>
<tr><td>00101</td><td>ADC5</td></tr>
<tr><td>00110</td><td>ADC6</td></tr>
<tr><td>00111</td><td>ADC7</td></tr>
<tr><td>01000</td><td></td></tr>
<tr><td>01001</td><td></td></tr>
<tr><td>01010</td><td></td></tr>
<tr><td>01011</td><td></td></tr>
<tr><td>01100</td><td></td></tr>
<tr><td>01101</td><td></td></tr>
<tr><td>01110</td><td></td></tr>
<tr><td>01111</td><td></td></tr>
<tr><td>10000</td><td></td><td>ADC0</td><td>ADC1</td></tr>
<tr><td>10001</td><td></td><td>ADC1</td><td>ADC1</td></tr>
</table>

ADC Control and Status Register A – ADCSRA

Bit	7	6	5	4	3	2	1	0	
	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0	ADCSRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

- **Bit 7 – ADEN: ADC Enable**

Writing this bit to one enables the ADC. By writing it to zero, the ADC is turned off. Turning the ADC off while a conversion is in progress, will terminate this conversion.

- **Bit 6 – ADSC: ADC Start Conversion**

In Single Conversion mode, write this bit to one to start each conversion. In Free Running mode, write this bit to one to start the first conversion. The first conversion after ADSC has been written after the ADC has been enabled, or if ADSC is written at the same time as the ADC is enabled, will take 25 ADC clock cycles instead of the normal 13. This first conversion performs initialization of the ADC.

ADSC will read as one as long as a conversion is in progress. When the conversion is complete, it returns to zero. Writing zero to this bit has no effect.

- **Bit 5 – ADATE: ADC Auto Trigger Enable**

When this bit is written to one, Auto Triggering of the ADC is enabled. The ADC will start a conversion on a positive edge of the selected trigger signal. The trigger source is selected by setting the ADC Trigger Select bits, ADTS in ADCSRB.

- **Bit 4 – ADIF: ADC Interrupt Flag**

This bit is set when an ADC conversion completes and the Data Registers are updated. The ADC Conversion Complete Interrupt is executed if the ADIE bit and the I-bit in SREG are set. ADIF is cleared by hardware when executing the corresponding interrupt handling vector. Alternatively, ADIF is cleared by writing a logical one to the flag. Beware that if doing a Read-Modify-Write on ADCSRA, a pending interrupt can be disabled. This also applies if the SBI and CBI instructions are used.

- **Bit 3 – ADIE: ADC Interrupt Enable**

When this bit is written to one and the I-bit in SREG is set, the ADC Conversion Complete Interrupt is activated.

- **Bits 2:0 – ADPS2:0: ADC Prescaler Select Bits**

These bits determine the division factor between the XTAL frequency and the input clock to the ADC.

Table 91. ADC Prescaler Selections

ADPS2	ADPS1	ADPS0	Division Factor
0	0	0	2
0	0	1	2
0	1	0	4
0	1	1	8
1	0	0	16
1	0	1	32
1	1	0	64
1	1	1	128

The ADC Data Register – ADCL and ADCH

ADLAR = 0

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	–	–	ADC9	ADC8	ADCH
	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADC1	ADC0	ADCL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R	
	R	R	R	R	R	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

ADLAR = 1

Bit	15	14	13	12	11	10	9	8	
	ADC9	ADC8	ADC7	ADC6	ADC5	ADC4	ADC3	ADC2	ADCH
	ADC1	ADC0	–	–	–	–	–	–	ADCL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R	R	R	R	
	R	R	R	R	R	R	R	R	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

When an ADC conversion is complete, the result is found in these two registers.When ADCL is read, the ADC Data Register is not updated until ADCH is read. Consequently, if the result is left adjusted and no more than 8-bit precision is required, it is sufficient to read ADCH. Otherwise, ADCL must be read first, then ADCH.

The ADLAR bit in ADMUX, and the MUXn bits in ADMUX affect the way the result is read from the registers. If ADLAR is set, the result is left adjusted. If ADLAR is cleared (default), the result is right adjusted.

- **ADC9:0: ADC Conversion Result**

These bits represent the result from the conversion, as detailed in “ADC Conversion Result” on page 204.

APPENDIX 4
MAX6675 Data Sheet

maxim integrated™

MAX6675

Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

General Description

The MAX6675 performs cold-junction compensation and digitizes the signal from a type-K thermocouple. The data is output in a 12-bit resolution, SPI™-compatible, read-only format.

This converter resolves temperatures to 0.25°C, allows readings as high as +1024°C, and exhibits thermocouple accuracy of 8LSBs for temperatures ranging from 0°C to +700°C.

The MAX6675 is available in a small, 8-pin SO package.

Applications

Industrial

Appliances

HVAC

Automotive

SPI is a trademark of Motorola, Inc.

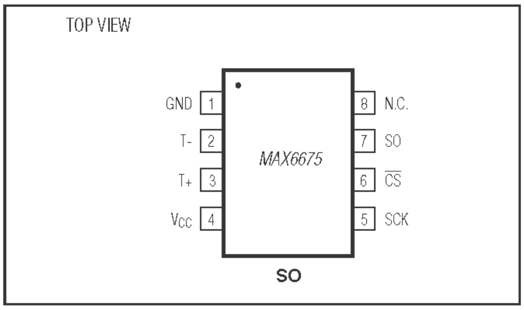
Features

- ♦ Direct Digital Conversion of Type -K Thermocouple Output
- ♦ Cold-Junction Compensation
- ♦ Simple SPI-Compatible Serial Interface
- ♦ 12-Bit, 0.25°C Resolution
- ♦ Open Thermocouple Detection

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX6675ISA	-20°C to +85°C	8 SO

Pin Configuration



For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maximintegrated.com.

19-2235; Rev 1; 3/02

MAX6675

Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{CC} to GND) .... -0.3V to +6V
SO, SCK, $\overline{CS}$, T-, T+ to GND ....-0.3V to V_{CC} + 0.3V
SO Current 50mA
ESD Protection (Human Body Model) .... ±2000V
Continuous Power Dissipation (T_A = +70°C)
8-Pin SO (derate 5.88mW/°C above +70°C) 471mW
Operating Temperature Range ....-20°C to +85°C
Storage Temperature Range ....-65°C to +150°C
Junction Temperature .... +150°C
SO Package
Vapor Phase (60s) . ...+215°C
Infrared (15s) ....+220°C
Lead Temperature (soldering, 10s) .... +300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.0V to +5.5V, T_A = -20°C to +85°C, unless otherwise noted. Typical values specified at +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Temperature Error		$T_{THERMOCOUPLE}$ = +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-5		+5	LSB
			V_{CC} = +5V	-6		+6	
		$T_{THERMOCOUPLE}$ = 0°C to +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-8		+8	
			V_{CC} = +5V	-9		+9	
		$T_{THERMOCOUPLE}$ = +700°C to +1000°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-17		+17	
			V_{CC} = +5V	-19		+19	
Thermocouple Conversion Constant					10.25		µV/LSB
Cold-Junction Compensation Error		T_A = -20°C to +85°C (Note 2)	V_{CC} = +3.3V	-3.0		+3.0	°C
			V_{CC} = +5V	-3.0		+3.0	
Resolution					0.25		°C
Thermocouple Input Impedance					60		kΩ
Supply Voltage	V_{CC}			3.0		5.5	V
Supply Current	I_{CC}				0.7	1.5	mA
Power-On Reset Threshold		V_{CC} rising		1	2	2.5	V
Power-On Reset Hysteresis					50		mV
Conversion Time		(Note 2)			0.17	0.22	s
SERIAL INTERFACE							
Input Low Voltage	V_{IL}					0.3 x V_{CC}	V
Input High Voltage	V_{IH}			0.7 x V_{CC}			V
Input Leakage Current	I_{LEAK}	V_{IN} = GND or V_{CC}				±5	µA
Input Capacitance	C_{IN}				5		pF

MAX6675

Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

Pin Description

PIN	NAME	FUNCTION
1	GND	Ground
2	T-	Alumel Lead of Type-K Thermocouple. Should be connected to ground externally.
3	T+	Chromel Lead of Type-K Thermocouple
4	V_{CC}	Positive Supply. Bypass with a 0.1µF capacitor to GND.
5	SCK	Serial Clock Input
6	$\overline{CS}$	Chip Select. Set $\overline{CS}$ low to enable the serial interface.
7	SO	Serial Data Output
8	N.C.	No Connection

Detailed Description

The MAX6675 is a sophisticated thermocouple-to-digital converter with a built-in 12-bit analog-to-digital converter (ADC). The MAX6675 also contains cold-junction compensation sensing and correction, a digital controller, an SPI-compatible interface, and associated control logic.

The MAX6675 is designed to work in conjunction with an external microcontroller (µC) or other intelligence in thermostatic, process-control, or monitoring applications.

Temperature Conversion

The MAX6675 includes signal-conditioning hardware to convert the thermocouple's signal into a voltage compatible with the input channels of the ADC. The T+ and T- inputs connect to internal circuitry that reduces the introduction of noise errors from the thermocouple wires.

Before converting the thermoelectric voltages into equivalent temperature values, it is necessary to compensate for the difference between the thermocouple cold-junction side (MAX6675 ambient temperature) and a 0°C virtual reference. For a type-K thermocouple, the voltage changes by 41µV/°C, which approximates the thermocouple characteristic with the following linear equation:

$$V_{OUT} = (41\mu V / °C) \times (T_R - T_{AMB})$$

Where:

V_{OUT} is the thermocouple output voltage (µV).

T_R is the temperature of the remote thermocouple junction (°C).

T_{AMB} is the ambient temperature (°C).

Cold-Junction Compensation

The function of the thermocouple is to sense a difference in temperature between two ends of the thermocouple wires. The thermocouple's hot junction can be read from 0°C to +1023.75°C. The cold end (ambient temperature of the board on which the MAX6675 is mounted) can only range from -20°C to +85°C. While the temperature at the cold end fluctuates, the MAX6675 continues to accurately sense the temperature difference at the opposite end.

The MAX6675 senses and corrects for the changes in the ambient temperature with cold-junction compensation. The device converts the ambient temperature reading into a voltage using a temperature-sensing diode. To make the actual thermocouple temperature measurement, the MAX6675 measures the voltage from the thermocouple's output and from the sensing diode. The device's internal circuitry passes the diode's voltage (sensing ambient temperature) and thermocouple voltage (sensing remote temperature minus ambient temperature) to the conversion function stored in the ADC to calculate the thermocouple's hot-junction temperature.

Optimal performance from the MAX6675 is achieved when the thermocouple cold junction and the MAX6675 are at the same temperature. Avoid placing heat-generating devices or components near the MAX6675 because this may produce cold-junction-related errors.

Digitization

The ADC adds the cold-junction diode measurement with the amplified thermocouple voltage and reads out the 12-bit result onto the SO pin. A sequence of all zeros means the thermocouple reading is 0°C. A sequence of all ones means the thermocouple reading is +1023.75°C.

MAX6675
Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

Applications Information

Serial Interface

The *Typical Application Circuit* shows the MAX6675 interfaced with a microcontroller. In this example, the MAX6675 processes the reading from the thermocouple and transmits the data through a serial interface. Force $\overline{CS}$ low and apply a clock signal at SCK to read the results at SO. Forcing $\overline{CS}$ low immediately stops any conversion process. Initiate a new conversion process by forcing $\overline{CS}$ high.

Force $\overline{CS}$ low to output the first bit on the SO pin. A complete serial interface read requires 16 clock cycles. Read the 16 output bits on the falling edge of the clock. The first bit, D15, is a dummy sign bit and is always zero. Bits D14–D3 contain the converted temperature in the order of MSB to LSB. Bit D2 is normally low and goes high when the thermocouple input is open. D1 is low to provide a device ID for the MAX6675 and bit D0 is three-state.

Figure 1a is the serial interface protocol and Figure 1b shows the serial interface timing. Figure 2 is the SO output.

Open Thermocouple

Bit D2 is normally low and goes high if the thermocouple input is open. In order to allow the operation of the open thermocouple detector, T- must be grounded. Make the ground connection as close to the GND pin as possible.

Noise Considerations

The accuracy of the MAX6675 is susceptible to power-supply coupled noise. The effects of power-supply noise can be minimized by placing a 0.1µF ceramic bypass capacitor close to the supply pin of the device.

Thermal Considerations

Self-heating degrades the temperature measurement accuracy of the MAX6675 in some applications. The magnitude of the temperature errors depends on the thermal conductivity of the MAX6675 package, the mounting technique, and the effects of airflow. Use a large ground plane to improve the temperature measurement accuracy of the MAX6675.

The accuracy of a thermocouple system can also be improved by following these precautions:

- Use the largest wire possible that does not shunt heat away from the measurement area.
- If small wire is required, use it only in the region of the measurement and use extension wire for the region with no temperature gradient.
- Avoid mechanical stress and vibration, which could strain the wires.
- When using long thermocouple wires, use a twisted-pair extension wire.
- Avoid steep temperature gradients.
- Try to use the thermocouple wire well within its temperature rating.
- Use the proper sheathing material in hostile environments to protect the thermocouple wire.
- Use extension wire only at low temperatures and only in regions of small gradients.
- Keep an event log and a continuous record of thermocouple resistance.

Reducing Effects of Pick-Up Noise

The input amplifier (A1) is a low-noise amplifier designed to enable high-precision input sensing. Keep the thermocouple and connecting wires away from electrical noise sources.

Chip Information

TRANSISTOR COUNT: 6720

PROCESS: BiCMOS