REMOTE TEMPERATURE MONITORING AND ANALYSIS OF THERMOFORMING PROCESS.

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REMOTE TEMPERATURE MONITORING AND ANALYSIS OF THERMOFORMING PROCESS.

MUHAMMAD FAIZ BIN AB. RAHIM

Thesis submitted in fulfillment of the requirements
for the award of B.ENG (HONS.) MECHATRONICS

Faculty of Manufacturing Engineering
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UNIVERSITI MALAYSIA PAHANG
FACULTY OF MANUFACTURING ENGINEERING

I certify that the project entitled *“Remote Temperature Monitoring and Analysis of Thermoforming Process”* is written by *Muhammad Faiz Bin Ab. Rahim*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Manufacturing Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering.

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ABSTRACT

Web-based Graphical User Interface for Manufacturing Process is one of the latest features to be implemented on most industry's machine recently due to availability of wide Internet network. The concept of connecting object to Internet network has been introduced by Kevin Ashton under the term of “Internet of Thing”. In this project, temperature monitoring devices for thermoforming machine heating section is being design and builds to measure temperature respond of radiation and convection heat transfer using thermocouples. The focuses on this project is to produce low cost data acquisition system using the spark core microcontroller that can display and record data remotely. It was found that using this system it enables far distance monitoring operation yet only suitable for certain type of process that perform at low response.

ABSTRAK

Antara muka pengunaa berasaskan grafik mengunakan komponent laman web di adaptasi untuk proses pembuatan adalah salah satu ciri-ciri terkini yang dilaksanakan pada kebanyakan mesin industri baru-baru ini kerana adanya rangkaian internet lebar. Konsep menghubungkan objek ke rangkaian internet telah diperkenalkan oleh Kevin Ashton mengunnakan istilah "Internet of Thing". Dalam projek ini, peranti pemantauan suhu pada bahagian pemanasan alat “thermoforming” di reka bentuk dan dibina untuk mengukur suhu radiasi dan konveksi pemindahan haba menggunakan penganding suhu. Fokus projek ini adalah untuk menghasilkan peranti kos rendah sistem merekod data menggunakan mikropengawal model Spark Core yang boleh memaparkan dan merekod data pada jarak jauh. Ia telah mendapati bahawa menggunakan sistem ini, membolehkan operasi pemantauan pada jarak jauh tetapi hanya sesuai untuk jenis proses tertentu yang berlaku pada tindak .

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LIST OF SYMBOLS

dBm	Decibel-milliwatts
°*C*	The degree Celsius
T_R	The temperature of the remote thermocouple junction.
T_{AMB}	The ambient temperature.
μV	MicroVolt
KB	Kilobyte
MHz	Mega hertz
Mbps	Megabit per second

LIST OF ABBREVIATIONS

ADC	Analog to digital converter
APP	Application
ARM	Advance RISC Machine
BIT	Binary digit
DAQ	Data acquisition system
EMF	Electromotive force
EPROM	Erasable programmable read only memory
GND	Ground
GUI	Graphical User Interface
I/O	Input or output
IEEE	Institute of Electrical and Electronics Engineers
IDE	Integrated development environment
IOT	Internet of things
Op-amp	Operational amplifier
RAM	Random Access Memory
ROM	Read-only memory
SC	Seedbeck coefficient
TC	Thermocouple
V	Voltage
Vcc	Positive supply voltage
Vee	Emitter supply Voltage
V_{OUT}	Thermocouple output voltage
Vss	Negative Supply Voltage

Chapter 1

INTRODUCTION

1.1 Project Background

Implementation of latest technology in manufacturing process can improve productivity of the process. A lot of new features have been upgrade to manufacturing process system from year to year by engineer make the process more accurate, efficient, safe, and flexible related increase in the productivity. Latest microcontroller technology that integrated with wireless communication can be used as a platform to increase the monitoring capability.

Current assessable technology provides potential for remote integration and collaboration in manufacturing applications. The remote technology converts information and represent it in form of real-time visual information to the user which that can be accessed at different location and multi view display. This technology gives the advantage to prevent hazard of the emission or radiation where the machine operator will directly be exposed as he or she go near the machine to measure or operate the machine for certain cases.

For this project, a remote system to monitor the conventional thermoforming equipment will be developed and implement. The projects are improvement of conventional thermoforming equipment develop by previous student that used the wired data acquisition system to monitor the heat transfer on thermoforming process. The manual and decentralized monitoring system for this equipment can be considered as unproductive if the number of machine is high and being us for high scale production.

1.2 Problem Statement

In performing manufacturing process, machine operator facing difficulty in accessing the machine or equipment from different location and the monitoring process needs to done near the machine in identifying thermal characteristic of thermoforming process.

1.3 Project Objective

The objectives of this project are:

1. To develop hardware and software for remote monitoring system of thermoforming equipment.
2. To analysis the temperature responds on thermoforming process.

1.3 Project Scope

The scopes of this project are as follows:

1. Create software coding for monitor and control the thermoforming equipment.
2. Link the machine input and output data with the computer and mobile device remotely.
3. Analysis the temperature on thermoforming process that produces by the equipment.

1.5 Thesis Outline

This thesis is classified into five chapters. The contents of each chapter are summarized as below:

Chapter 1 briefs the introduction of the project. The background, objective, problem statement, scope of project summarizes the content of thesis are explained in this chapter.

Chapter 2 consist of the literature review that made from several journals and article that been refer which elaborates the recent research on the technology and also consist of the methodologies that has been applied in this project

Chapter 3 explains the hardware and software design of the project. In hardware design, will be focusing on the hardware that link between machine and display device. For software design, the programming of the GUI will be explained. The connections of hardware between the sensor and the thermoforming equipment are shown in circuit schematic diagram.

Chapter 4 will show all the results and the analysis of the project. All of the result obtains will be analyzed and the comment will be given based on the result getting.

Chapter 5 concludes the outcome of this project. It also includes the recommendations on this project for future works to improve the system.

CHAPTER 2

LITERATURE REVIEW

This chapter mainly about combining latest and previous information in this study which will summarize the important information regarding several fields involved in this project and it helps to elaborate certain term for understanding. Each category in this chapter will be discussed in detail about topics related which is microcontroller, internet protocol, web server, concept of data acquisition, multiplexer and sensor.

2.1 Introduction.

The combination of computers, multimedia and the Internet have provided great potential for remote integration and collaboration in business and manufacturing applications. Monitoring technique using the Internet can give advantage to the design and manufacturing productivity, economy, and speed, as well as provided collaborative real-time working (Hongbo Lan, 2009).

2.2 Internet of Thing.

The technology of traditional Internet has come to edge of maximize usage where it will fuse into a smart Internet of Things (IoT) exist by digitalized communication of various objects in the physical world. The IoT is generally set up of devices and objects contain a digital data processor or embedded that interact by other digital device such as mobile phone or personal computer using communication mechanism, mostly applying wireless connection.

The IoT giving the advantage of display unseen physical properties of the object which creating different way to interact. This creates new type of possibilities in internet application which make the thing’s information able to be accessed globally on the network.

The term Internet of Things was coined and first used by Kevin Ashton over a decade ago to attributes by being an Internet application and handle the thing's information.

2.3 Spark Core v1.0 Microcontrollers.

In this project, the microcontrollers playing an extremely important role as to link between the equipment to graphical user interface. Spark core used STM32F103CB chip which is ARM 32-bit Cortex M3 based microcontroller as a central processing unit operate at 72 MHz. This microcontroller has been attached with Wi-Fi module model Texas Instruments SimpleLink CC3000 as to give ability to communicate thought IEEE 802.11 wireless protocol so the process of interfacing the microcontroller on the internet became easier. This Wi-Fi module has performance of transmitting power communicate +18.0 dBm at speed of 11 Mbps Complementary Code Keying and receiver sensitivity detect –88 dBm with 8% Packet Error Data at 11 Mbps. It has 8 digital I/O and 8 analog inputs with 12-bit ADC. The I/O pin configuration is shown in Figure 2.1. The microcontroller operates at 3.3V DC supply voltage connected with on board power regulator. It has 128 KB of Flash and 20 KB of RAM internal memory and 2MB of external flash EEPROM supplied by CC3000.

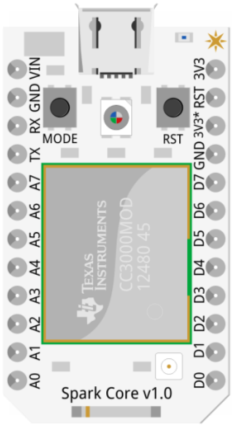


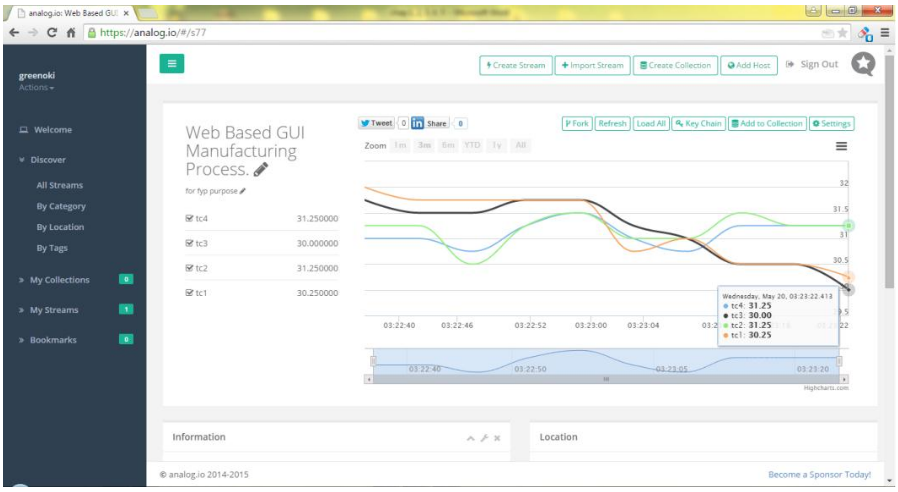
Figure 2.1: Spark Core v1.0 Microcontroller.

Source: Beri (n.d.). Spark Core Pin Diagram.
Reverted from http://docs.particle.io/assets/images/spark-pinout.png [Accessed 8 June 2015]

2.4 Cloud Server.

Cloud server works as a distribution platform to distribute data from machine to user. The resource for cloud server usage can be tuned by a decrease or increase accordingly, making it more cost-effective and more flexible to user. The capacity of storage and bandwidth can be automatically increased to match that demand without this needing to be paid for on a permanent basis.

The different of cloud server compare to dedicated servers, cloud servers can be run on a virtualization manager where it can control the capacity of operating systems so it is allocated based on a particular client if and when only it is needed. Cloud hosting provides multiple cloud servers which communicate with each particular client. Another advantage of cloud sever is that when there is a spike in network traffic usage due to load, the additional capacity of resource will be temporarily allocated by a host server until it is no longer required. As the cloud servers work synchronize with other cloud server. If one server down or fails, others server will take its place continues backup the task.



Web Based GUI Manufacturing Process.

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Figure 2.2: Screenshot of web based GUI

Source: analog.io(n.d) [screenshot]

Reverted from https://analog.io/#/s77[Accessed 8 June 2015].

For the graphical user interface output, this project used free internet application from website “www.analog.io” which display the recorded data as shown in figure 2.2 that store in the “data.sparkfun.com” database.

User needs to create an account to register before they can use this web application. For “data.sparkfun.com” application, user needs to configure the input variable and the stream title before it generate public and private key for the application. The public key is used as stream identification and the private key is used to push or modified in the database.

2.5 Sensor

2.5.1 Thermocouple Overview

Figure 2.3: Type-T Thermocouple.

Source: Omega Engineering(n.d.). Ready Made Insulated Thermocouple

Reverted from http://www.omega.com/Temperature/images/5TC_l.jpp

Thermocouple is a device that being constructed with two different materials such as copper and constantan (Type T). The two dissimilar metals are contact together at the end of both wires with weld bead. This device being used to detect and responds toward the temperature change. If there is a temperature different between bead and thermocouple end, the thermocouple will output electrical voltage. The voltage generated by this condition is called thermoelectric effect or Seebeck effect. The phenomenon is discovered by German Physicist T.J Seebeck in 1821.

The voltage output from thermocouple during seedbeck effect is express in Eq. (2.0).

$$V_{OUT} = (SC\ \mu V / {}^{\circ}C) \times (T_R - T_{AMB}) \qquad (2.0)$$

2.6 Data acquisition

Data acquisition (DAQ) is the process of translating physical stimulus from the real world into electrical signals that are measured and converted into a digital representation for processing, analysis, and storage into computer memory (T. Sumphao, C. Thanachayanont, T. Seetawan, 2011).

2.7 Signal Conditioning.

Signal conditioning is a process transform real life input signal into the signal that can be read by data acquisition systems. Real input signal from the sensor is often has noise and produces the range of voltage that unsuitable for analog to digital converter (ADC) device to process. When using Thermocouple as sensor the output voltage from thermocouple produce the range in millivolt of output. This voltage need to be amplified at the range that suitable for ADC device. Figure 2.4 illustrate the basic signal conditioning connection for single thermocouple condition.

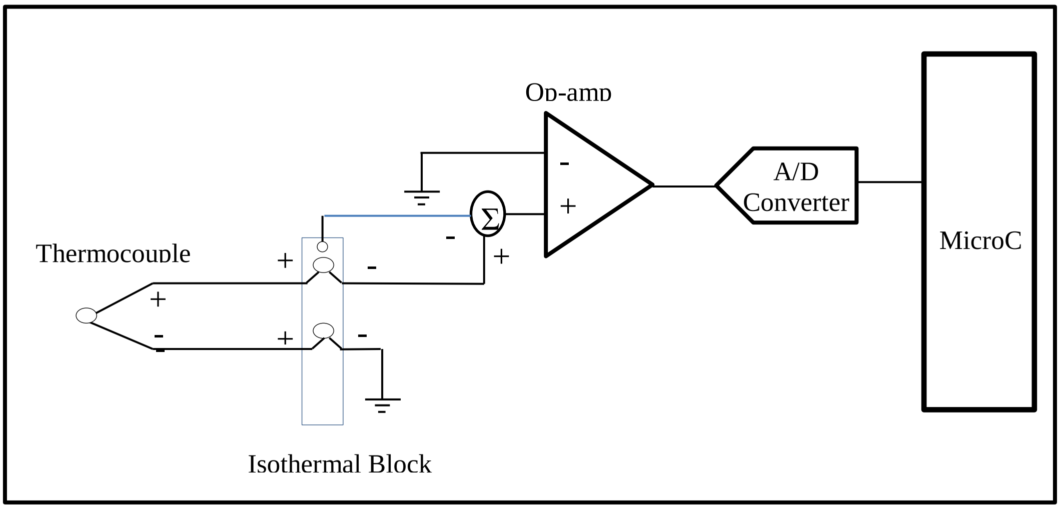

Figure 2.4: Basic signal conditioning connection.

2.8 Multiplexer Circuit.

Multiplexing is the universal term used to describe the operation of sending one or more analogue or digital signals over a common transmission line at different times or speeds**.** The 74HC4052 is a fast react silicon gate CMOS integrated circuit and is pin configuration is adaptable with the HEF4052B which suitable for this project. The IC is compliance with JEDEC standard no. 7A.

The 74HC4052 is dual 4-channel analog multiplexer with a common enable input (E). Each multiplexer has four separated inputs (nY0 and nY1) and single common output (nZ) control by two digital select inputs (Sn). Both channels will switch based on same digital select input. With E LOW, common output will enable according to the channel selected using S0 and S1 by condition low-impedance ON-state. With E HIGH, all output switches are in the high-impedance OFF-state, independent of S0 to S1.

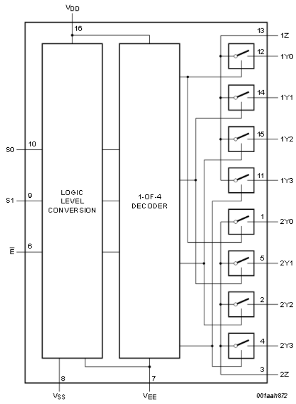

Figure 2.5: 74HC4052 Function diagram.

‘

Source: Philips Semiconductors (2004)

V_{CC} and GND are the main supply voltage input pins for the digital control inputs. The input ranges V_{CC} to GND are 2.0 V to 10.0 V for 74HC4052. The analog inputs and outputs nY0 to nY1, and nZ can swing between V_{CC} as a positive limit and V_{EE} as a negative limit. V_{CC} - V_{EE} may not exceed 10.0 V. Figure 2.5 shows the function diagram of the multiplexer operation where it consists of logic level conversion, 1 of 4 decoder and digital switch operate based on truth table show in Table 2.0.

Table 1.0: Truth Table for Multiplexer Output.

Input			CHANNEL BETWEEN
E	S1	S0	
L	L	L	nY0 and nZ
L	L	H	nY1 and nZ
L	H	L	nY2 and nZ
L	H	H	nY3 and nZ
H	X	X	none

Source: Philips Semiconductors (2004)

Note

H = HIGH voltage level
L = LOW voltage level
X = don’t care.

2.9 Offset calibration.

Measurement offset is due to amplifier, A/D converter and thermocouple uncertainty offsets in the system hardware. Due to the specific measurement processing used in the hardware, the resulting measurement offset is both range- and sample time-dependent. This error is corrected using normalized offset compensation which takes these dependences into account. Measurement offsets can be using the external measurement device as reference.

CHAPTER 3

METHODOLOGY

This chapter will describe the method to be used for this project. The project consists of hardware and software design, both of part will be explained in detailed along with figure related. The flow chart below shows the steps that have been taken in doing this project.

3.1 PROJECT FLOWCHART

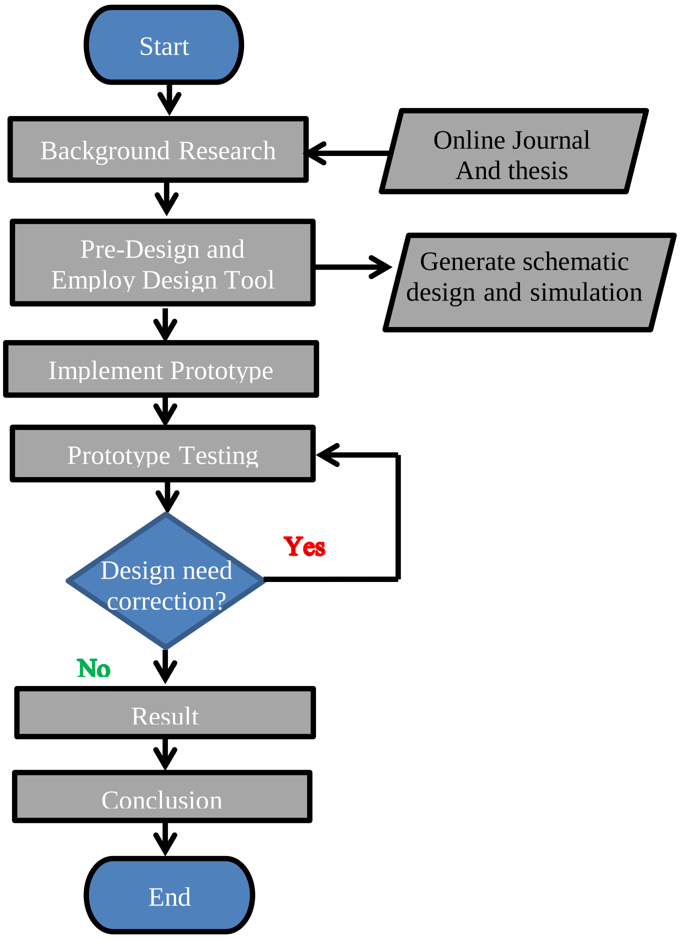

Figure 3.1: Overall project Implementation flowchart**.**

3.2 System Pre-Design

Before the fully system is developed several techniques had been used to achieve the complete system. Firstly, the part of the system is simulated using Proteus. In the first attempt using op-amp amplifier LM358 the output of the thermocouple has not fit to the thermocouple amplification and it found that this op-amp produce large signal noise. The amplification circuit of thermocouple is replaced with MAX 6675 module.

Secondly, the coding of signal between microcontroller and web server is developed to replicate the process of signal being transfer to web server using Arduino Uno, wamp server and web browser. In this process, wamp server is set up using php coding. The server fails to read data from serial port due to libraries limitation but can read the serial data on usb.

Finally, the system consisting arduino uno microcontroller, temperature sensor, computer is being integrated with readymade firmware and web application on “cloudduino.appspot.com” as shown in figure 3.2. In this stage, the web applications indicate the latency while using the serial communication over usb because the data need to process by computer before it sends to web graphical user interface. Due to this reason the project required microcontroller that directly connected to local network area and wide network area. The spark core microcontroller is used for next process.

Figure 3.2: Clouddunio Web Apps.

3.3 FRIMWARE PROGRAMMING

The firmware is the part in these devices where it provides the control program for the embedded system. Firmware is store in non-volatile memory devices such as flash memory, ROM or EPROM of the microcontroller.

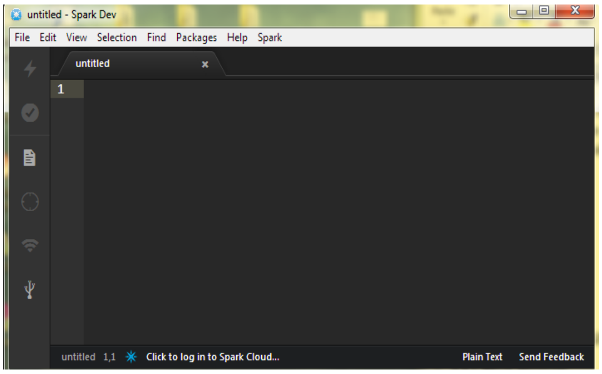

Figure 3.3: Spark DEV IDE.

The firmware is coded in c language using Spark Dev IDE shown in figure 3.2 and then the codes are being flashed into the microcontroller trough USB or WIFI connection. The device needs to be claimed using its security token before the user can start the process of flashing the code.

3.4 HARDWARE DESIGN

3.3.1 Block Diagram.

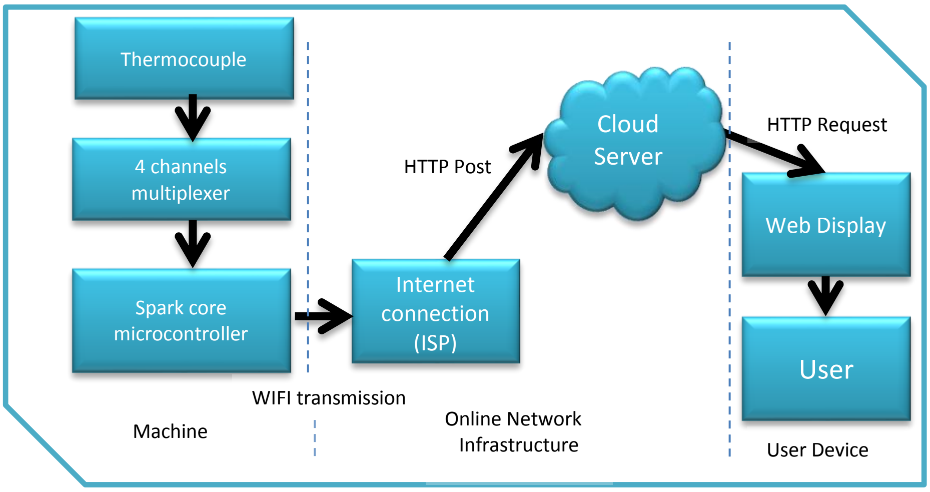

Figure 3.4: Block Diagram of the remote monitoring system.

The physical stimulus needs to travel through several stages before the user views the recorded data. The Figure 3.4 shown the flow of temperature data on the system used in this project. The temperature at thermocouple surrounding is converted to electrical signal as heat is transferred to end of the thermocouple tips. The signal than being amplified and microcontroller convert the signal to digital signal. The temperature value that being represented in the digital signal then posted to the cloud server thought Hypertext Transfer Protocol using Internet service provider connection linked to a local router WI-FI connection. The data is stored in a cloud server database. As the user browsed the web, the graphical interface viewing the graph as the representation of data collected.

3.4.2 Circuit Design.

For the circuit design, Proteus v7.1 Virtual System Modeling is used as to perform pre-design process before the real circuit is constructed. Proteus VSM provides assist in development platform for the embedded engineer. It allows user to simulate the effects of the circuit on the schematic that have created. Hardware design can be changed instantly by changing component values, adding new components or rewiring the schematic and deleting to the design. This gives flexibility to experiment with different ideas and to find the optimal design solution for the project. The schematic serves as a 'virtual prototype' for the firmware and it's quick and easy to make changes to either. Figure 3.5 show the printed circuit board design using this software. At first the schematic circuit is constructed in the software and after the component is being connected together based on its pin, the layout of the copper trace in the PCB is routed using the software. Details of design are shown in appendix G.

The complete circuit design that printed on gloss paper is transferred to the copper board for etching process. The component and terminal pin connector then being solder on the PCB.

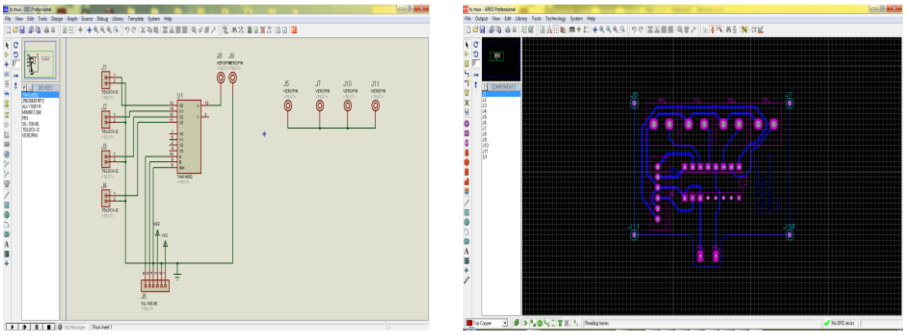

Figure 3.5: Screenshot of multiplexer design process.

3.5 Experimental Set up

By designing experiment set up to identify the temperature responds on the thermoforming machine heating section, four thermocouple are used to investigate the temperature characteristic using remote system configuration based on Figure 3.4. In this project, after the complete circuit is constructed the all components are being placed inside of the electrical box. Figure 3.6 show the overall project product.

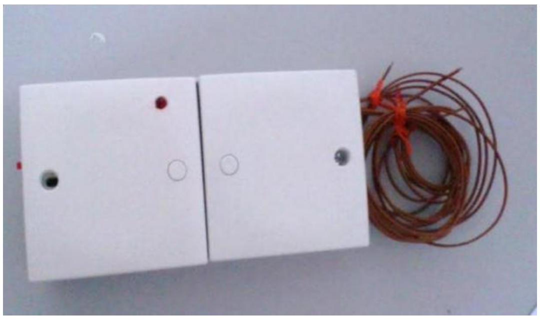

Figure 3.6: Overall Project Hardware.

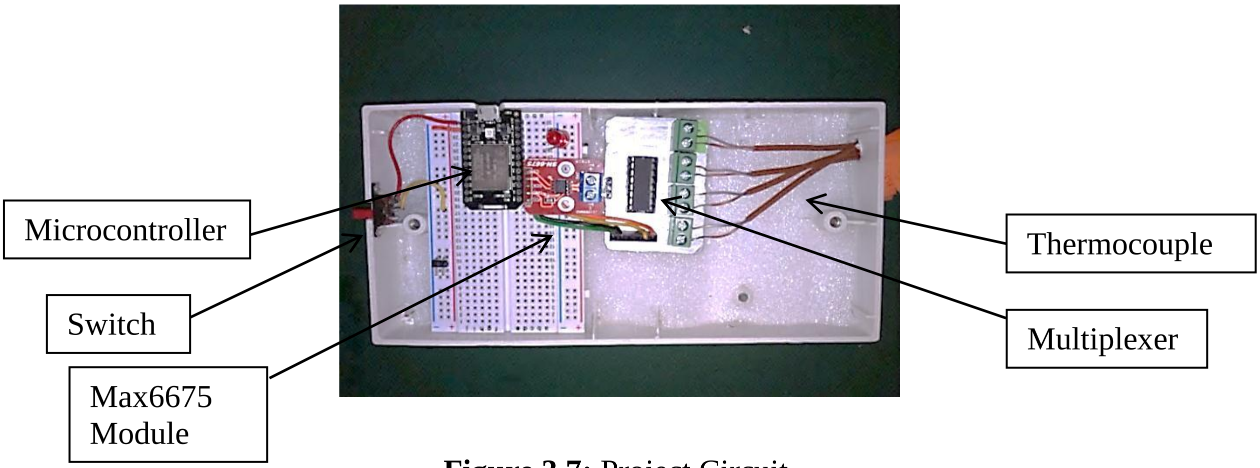

Figure 3.7: Project Circuit.

In Figure 3.7, show overall circuit position inside of electronic box consisting on/off switch, microcontroller, breadboard, multiplexer circuit, led and thermocouple. The end of thermocouple wire is attached to heating element section as shown in Figure 3.8. Four number of t-type thermocouple are being used in the experiment.

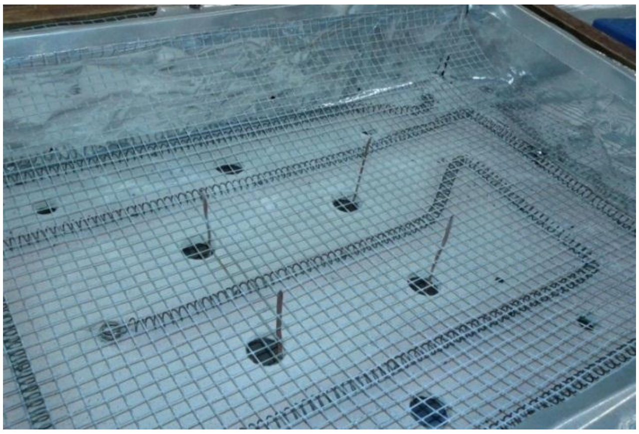

Figure 3.8: Thermocouple position on heating section.

Two type of experiment have been setup with different position of the thermocouple as show in figure 3.9 and 3.10. Each thermocouple is being placed in different quadrant at heating element section. The different of these two experiment only the change in position of thermocouple 1. Each thermocouple is elevated 5 cm above the heating element. The initial temperature of the heating element surrounding is based on room temperature which is 27 °C. The heating section is covered with an aluminum foil as to mimic the temperature during thermoforming process as show in figure 3.11. The aluminum foil is used to isolate the heated air from escaping the heating area.

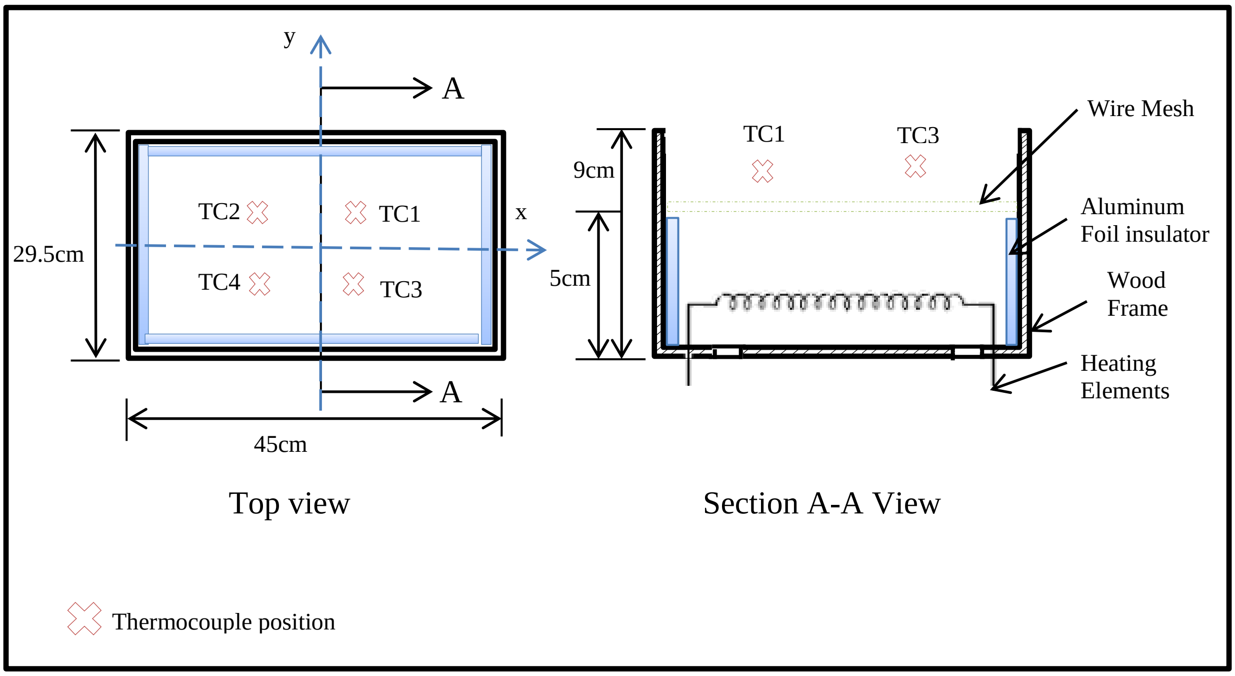

Figure 3.9: Thermocouple Position for Experiment 1 on Thermoforming Equipment Heating section.

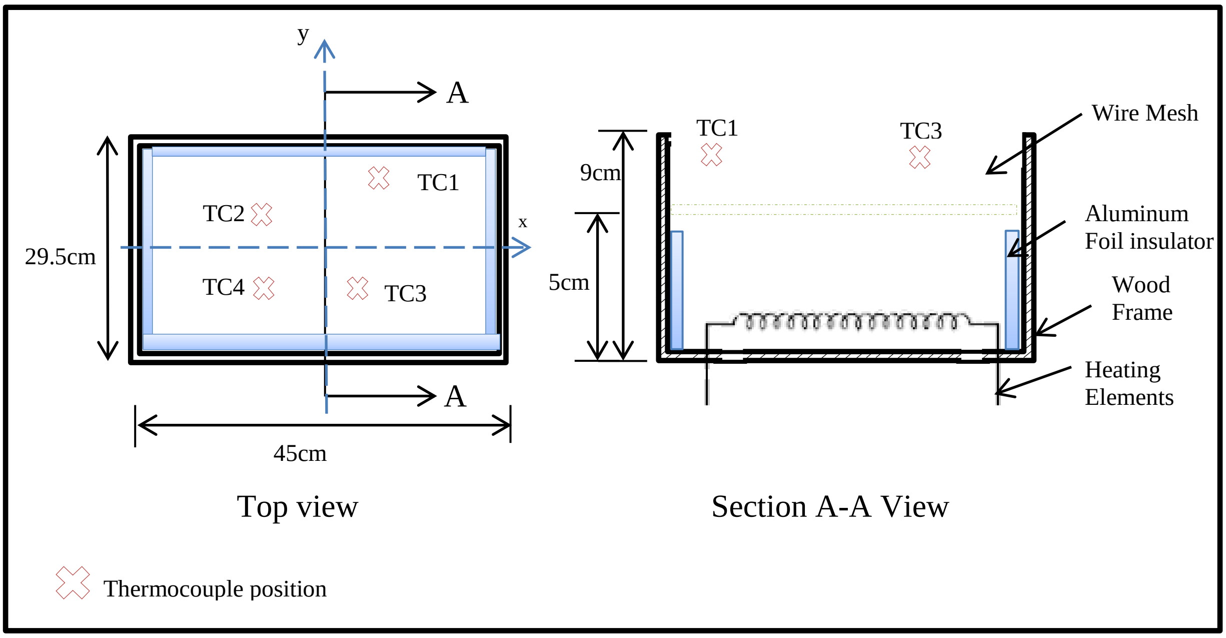

Figure 3.10: Thermocouple Position for Experiment 2

on Thermoforming Equipment Heating section.

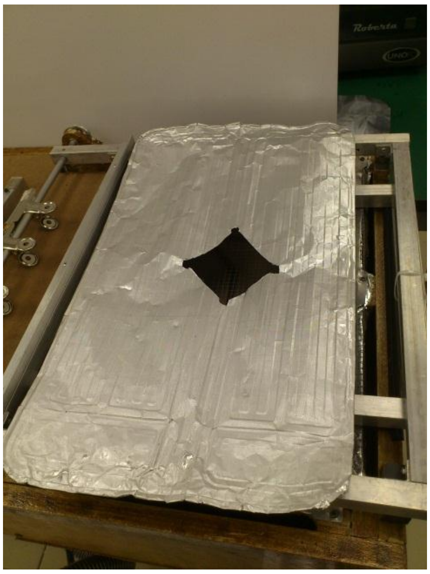

Figure 3.11: Heating element cover.

The coding of the firmware used in microcontroller is attached in Appendix E1, E2 and E3. As the spark core microcontroller power up, it will connect to Wi-Fi connection and send data to server and store the temperature data on database on “data.sparkfun.io” then the plotted graph will be display on web application under analog.io application.

Chapter 4

RESULT AND DISCUSSION

This chapter presents the outcome of project in terms of overall circuit construction as well as the time responds of thermocouple on remote system and performance of system.

4.1 Result

4.1.1 System Performance.

From the time stamp generated as can refer to appendix F1, the average time for microcontroller store data in the database are 4.9 second based on 75 data recorded and the shortest time is 2.7 second for experiment 1. The recorded data show the system error posting time around 11.9 and 28 second as appear in recorded data.

In experiment 2, the average the average time for microcontroller store data in the database are 4.5 second based on 94 data. The fastest time interval between the posts is 2.2 second. The time between post errors are 8.1 and 19.6 seconds.

From both experiment data tabulated it show that the time of data posting are inconsistence with the programmed coding. This is due to external network connection that limited by server and application provider.

4.3 Thermocouple Respond.

Based on an experiment setup:

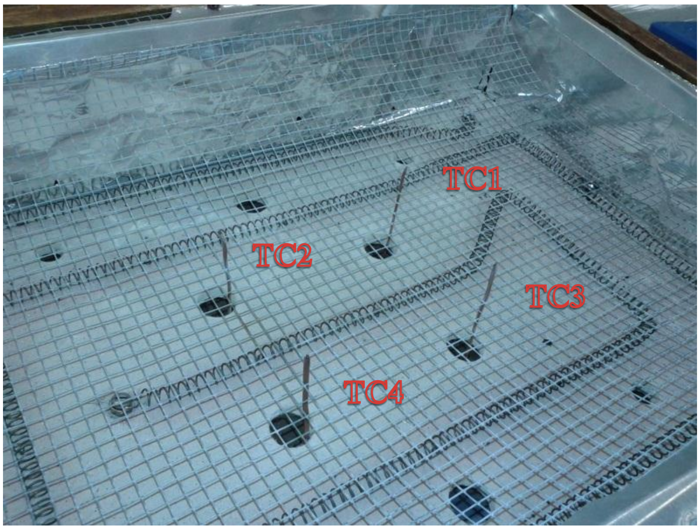

Figure 4.4: Thermocouple position on heating section for experiment 1.

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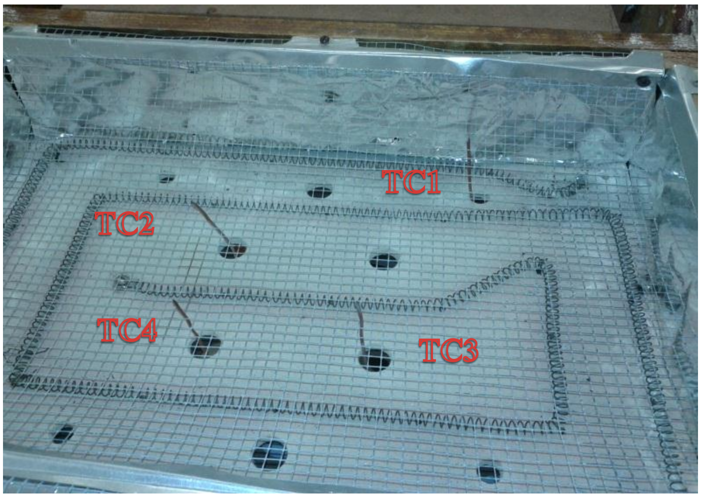


Figure 4.5: Thermocouple position on heating section for experiment 2.

Result explanation:

As the temperature history show in figure 4.5 and 4.6 the TC1 and TC3 have the close value to each other. Same goes to TC3 and TC4 it can be described as this following factor.

1) From figure 4.6 and 4.7, the convection and radiation heat transfer at TC1 and TC3 has close temperature and higher than TC2 and TC4 due to position near hotter section.

2) The timing of multiplexer switching might create an error in storing data process as the MAX6675 need amount of time to complete process temperature value. The stored data might interference with other thermocouple input. Other error factor form multiplexer is its unknown thermal EMF inside the multiplexer that might alter the recorded data.

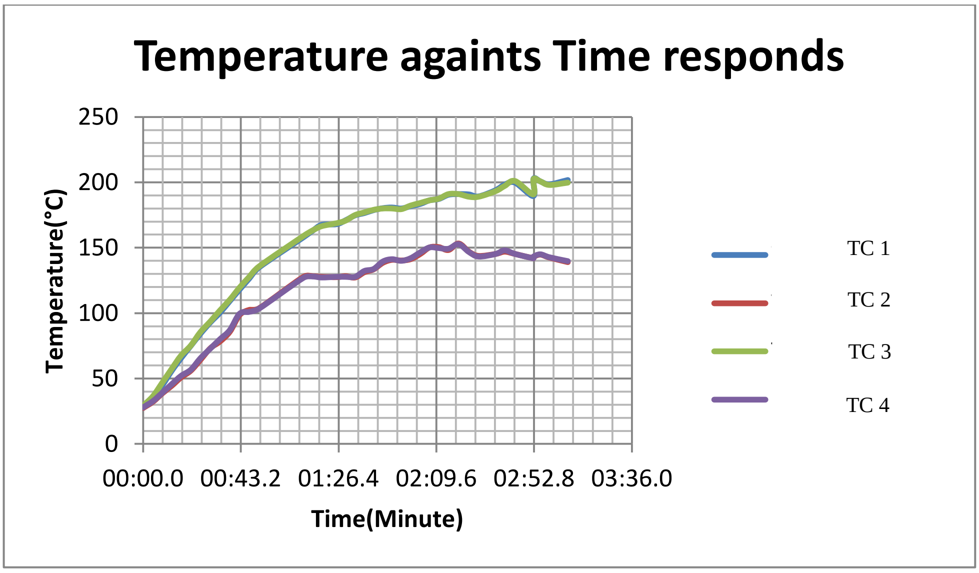


Figure 4.6: Temperature History for experiment 1.

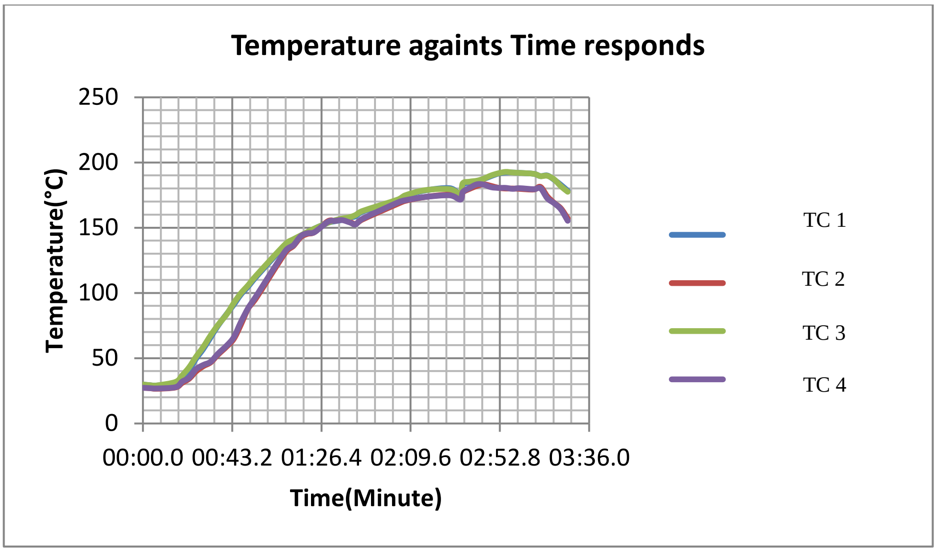


Figure 4.7: Temperature History for experiment 2.

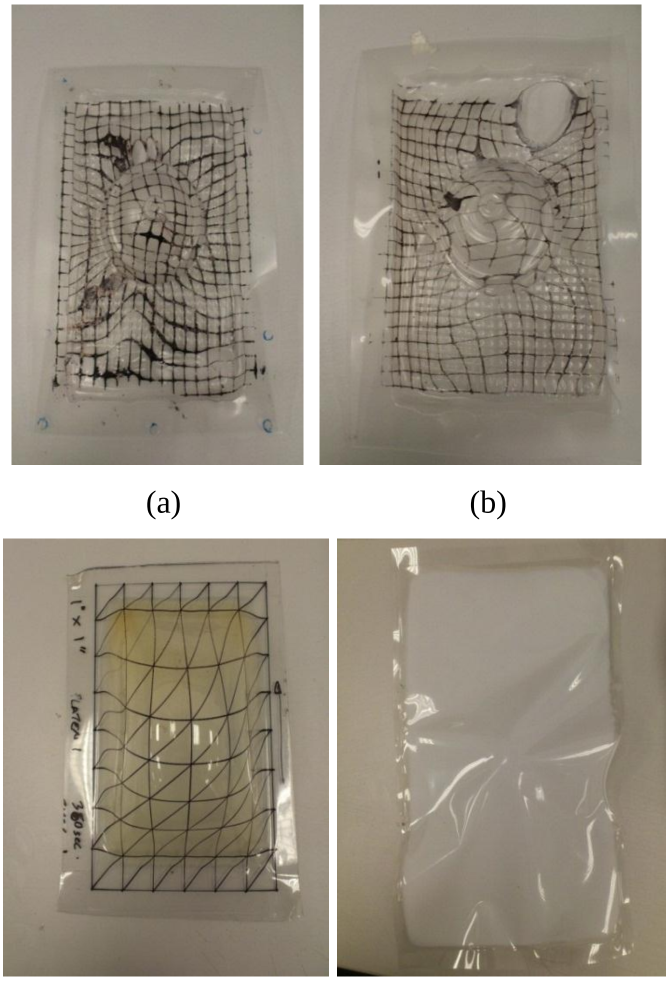
4.2 Discussion

The data are collected from sensor has a latency of approximately 4 second before it is stored in the database. This latency occurs due to cloud server limitation, network bandwidth speed, and user internet connection speed. This web based monitoring system will be improved and be more reliable as the suitable web server platform are being developed.

In the process of developing a device that has high precision and accuracy temperature recorder, It is found that if standard op-amp for signal conditioning are used it contribute to greater amount of noise and required higher amount of voltage supply to operate. The standard op-amp required to use a resistor and capacitor configuration as produce required amplification gain that has higher percentage of tolerance will affect the data accuracy.

Temperature distribution is one of the main factors that affect the finishing of thermoforming process. In thermoforming, different type of plastic sheet material required different range of temperature. In some condition if the material overheated the plastic sheet could melted as show in figure 4.8 (a) and (b). In figure 4.8(c), the plastic sheet change colour from transparent to pale brown after the plastic is heated. The heated sheet can face the problem where it is unable to forming due to the plastic not reaching the forming temperature.

By comparing the temperature history on the heating section and the effect on the plastic sheet, the temperature distribution show the un event heating could lead to defect in thermoforming process.



(a) (b)

(c) (d)

Figure 4.8: Plastic sheet profiles under thermoforming process (a) Plastic sheet over heated (b) Plastic sheet melting (c) Plastic sheet discolor. (d) Plastic sheet unable to form.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project demonstrates the concept of how to create the web base monitoring system that can be used in industries with its advantage and disadvantage of this system. From the project findings, the system limits the accuracy real-time data but extend the range of monitoring display. The system had worked according to its function but this system respond might not suitable for a short duration process and required fast responds. This type of system is suitable for the process that needed to operate at safe distance due to hazardous release and radiation that will affect health and alter the possibility to get unwanted disease.

5.2 Recommendation

Based on the finding on the temperature history it show that thermocouple at quadrant 1 and 4 are the good position to placed thermocouple for the thermoforming process. The selection are based on the position that has higher temperature value because as the oven heat the material the material melting profile on the plastic sheet most effected by high temperature position.

In this project, there are several improvements for future work that could be implementing to increase the capability of system from my point of view which are:

1. The temperature signal processing module could be upgrade to latest model which has better accuracy calibration and processing time.
2. The system could be integrated with other sensor and control component where the user input could be trigger using visual button.

3. Suitable dedicated platform server and network connection that promote high speed bandwidth could be implement or developing as to improve the system performance.

References

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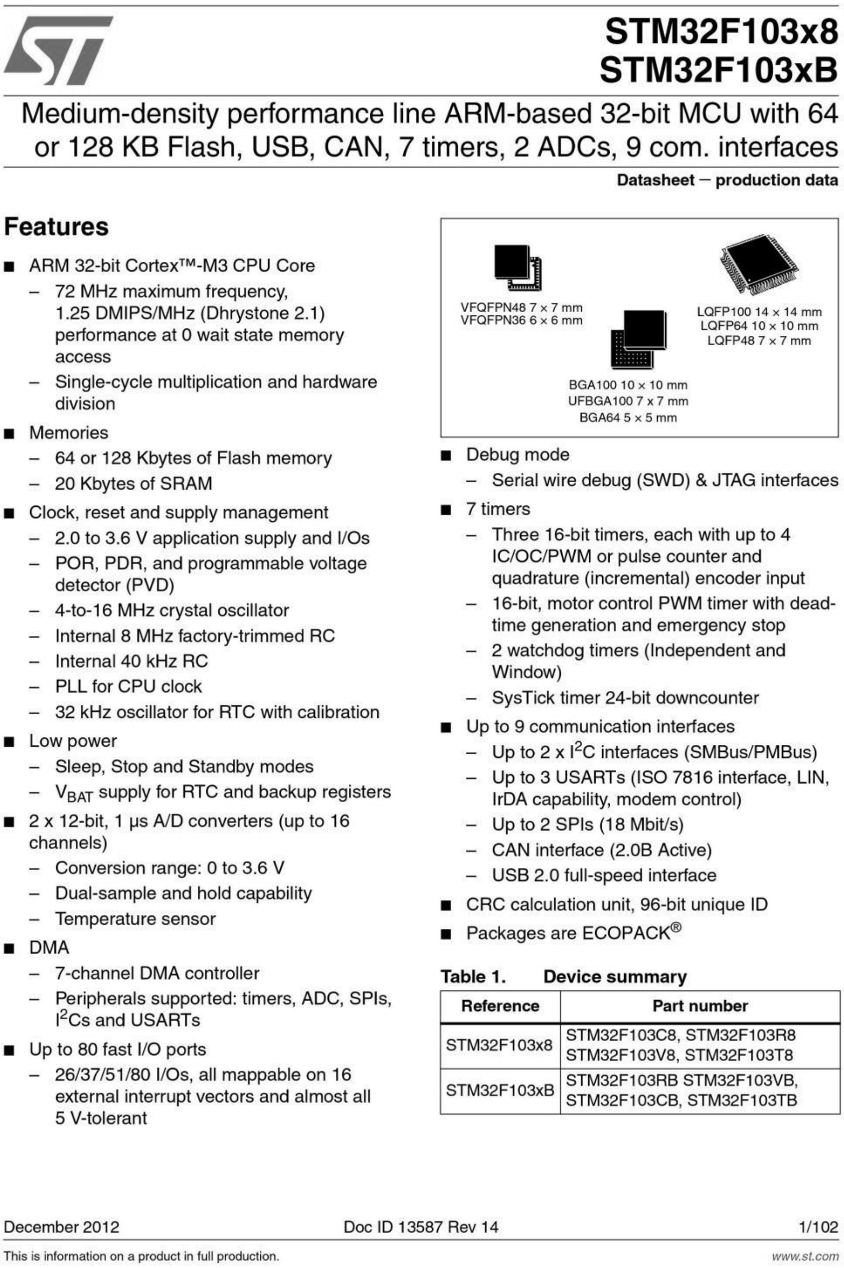
APPENDIX A1

Micrcontroller CPU datasheet



STM32F103x8
STM32F103xB

Medium-density performance line ARM-based 32-bit MCU with 64 or 128 KB Flash, USB, CAN, 7 timers, 2 ADCs, 9 com. interfaces

Datasheet − production data

Features

- ARM 32-bit Cortex™-M3 CPU Core
  - 72 MHz maximum frequency, 1.25 DMIPS/MHz (Dhrystone 2.1) performance at 0 wait state memory access
  - Single-cycle multiplication and hardware division
- Memories
  - 64 or 128 Kbytes of Flash memory
  - 20 Kbytes of SRAM
- Clock, reset and supply management
  - 2.0 to 3.6 V application supply and I/Os
  - POR, PDR, and programmable voltage detector (PVD)
  - 4-to-16 MHz crystal oscillator
  - Internal 8 MHz factory-trimmed RC
  - Internal 40 kHz RC
  - PLL for CPU clock
  - 32 kHz oscillator for RTC with calibration
- Low power
  - Sleep, Stop and Standby modes
  - V_{BAT} supply for RTC and backup registers
- 2 x 12-bit, 1 µs A/D converters (up to 16 channels)
  - Conversion range: 0 to 3.6 V
  - Dual-sample and hold capability
  - Temperature sensor
- DMA
  - 7-channel DMA controller
  - Peripherals supported: timers, ADC, SPIs, I^{2}Cs and USARTs
- Up to 80 fast I/O ports
  - 26/37/51/80 I/Os, all mappable on 16 external interrupt vectors and almost all 5 V-tolerant

VFQFPN48 7 × 7 mm
VFQFPN36 6 × 6 mm

LQFP100 14 × 14 mm
LQFP64 10 × 10 mm
LQFP48 7 × 7 mm

BGA100 10 × 10 mm
UFBGA100 7 x 7 mm
BGA64 5 × 5 mm

- Debug mode
  - Serial wire debug (SWD) & JTAG interfaces
- 7 timers
  - Three 16-bit timers, each with up to 4 IC/OC/PWM or pulse counter and quadrature (incremental) encoder input
  - 16-bit, motor control PWM timer with dead-time generation and emergency stop
  - 2 watchdog timers (Independent and Window)
  - SysTick timer 24-bit downcounter
- Up to 9 communication interfaces
  - Up to 2 x I^{2}C interfaces (SMBus/PMBus)
  - Up to 3 USARTs (ISO 7816 interface, LIN, IrDA capability, modem control)
  - Up to 2 SPIs (18 Mbit/s)
  - CAN interface (2.0B Active)
  - USB 2.0 full-speed interface
- CRC calculation unit, 96-bit unique ID
- Packages are ECOPACK®

Table 1. Device summary

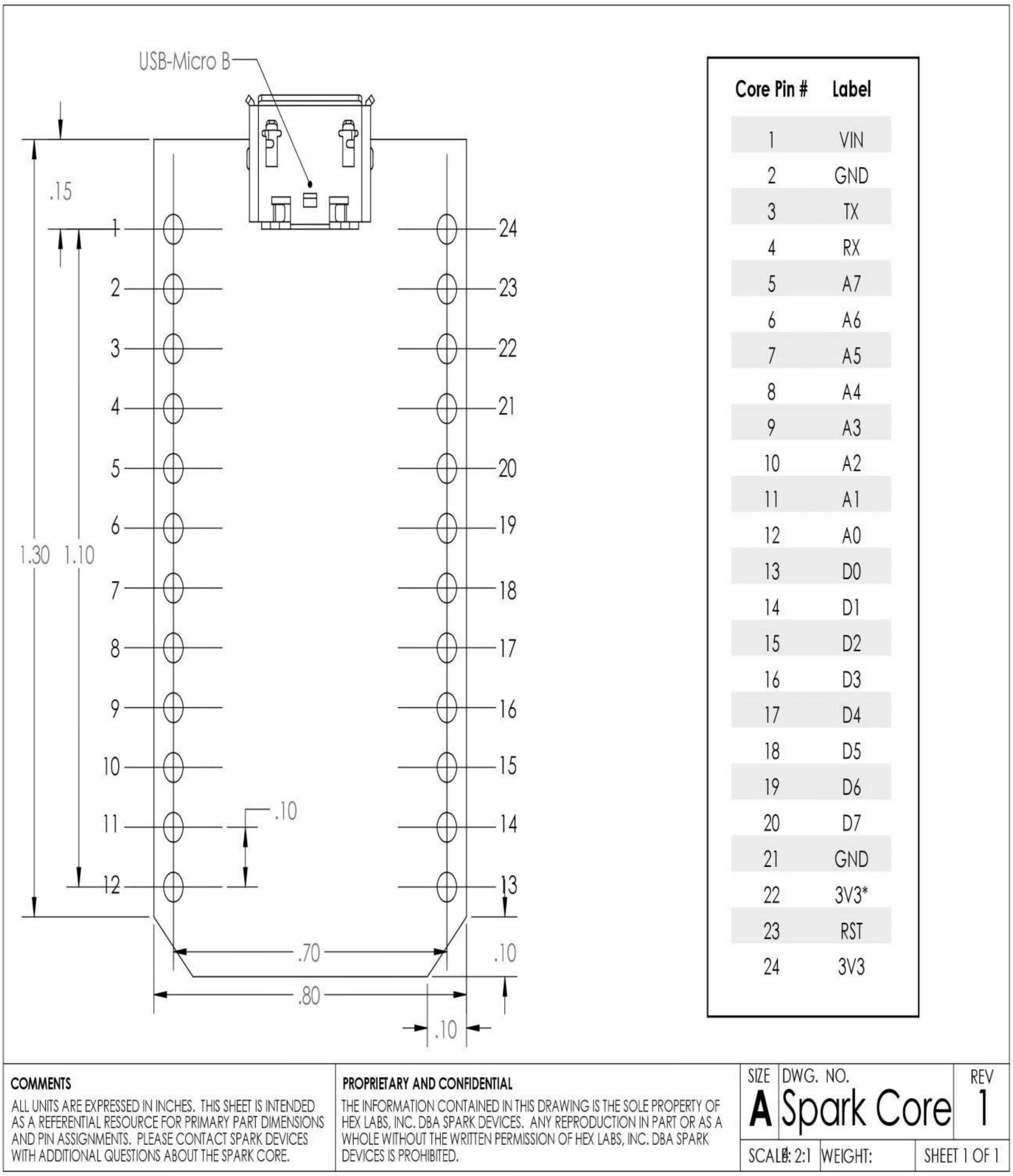
Reference	Part number
STM32F103x8	STM32F103C8, STM32F103R8 STM32F103V8, STM32F103T8
STM32F103xB	STM32F103RB STM32F103VB, STM32F103CB, STM32F103TB

This is information on a product in full production.

www.st.com

Appendix A2

Micrcontroller Mechanical Drawing



Core Pin #	Label
1	VIN
2	GND
3	TX
4	RX
5	A7
6	A6
7	A5
8	A4
9	A3
10	A2
11	A1
12	A0
13	D0
14	D1
15	D2
16	D3
17	D4
18	D5
19	D6
20	D7
21	GND
22	3V3*
23	RST
24	3V3

COMMENTS

ALL UNITS ARE EXPRESSED IN INCHES. THIS SHEET IS INTENDED AS A REFERENTIAL RESOURCE FOR PRIMARY PART DIMENSIONS AND PIN ASSIGNMENTS. PLEASE CONTACT SPARK DEVICES WITH ADDITIONAL QUESTIONS ABOUT THE SPARK CORE.

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF HEX LABS, INC. DBA SPARK DEVICES. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF HEX LABS, INC. DBA SPARK DEVICES IS PROHIBITED.

SIZE	DWG. NO.	REV
A	Spark Core	1

SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

APPENDIX B1

Datasheet of 74CH405

INTEGRATED CIRCUITS

DATA SHEET

74HC4052; 74HCT4052

Dual 4-channel analog multiplexer, demultiplexer

Product specification 2004 Nov 11

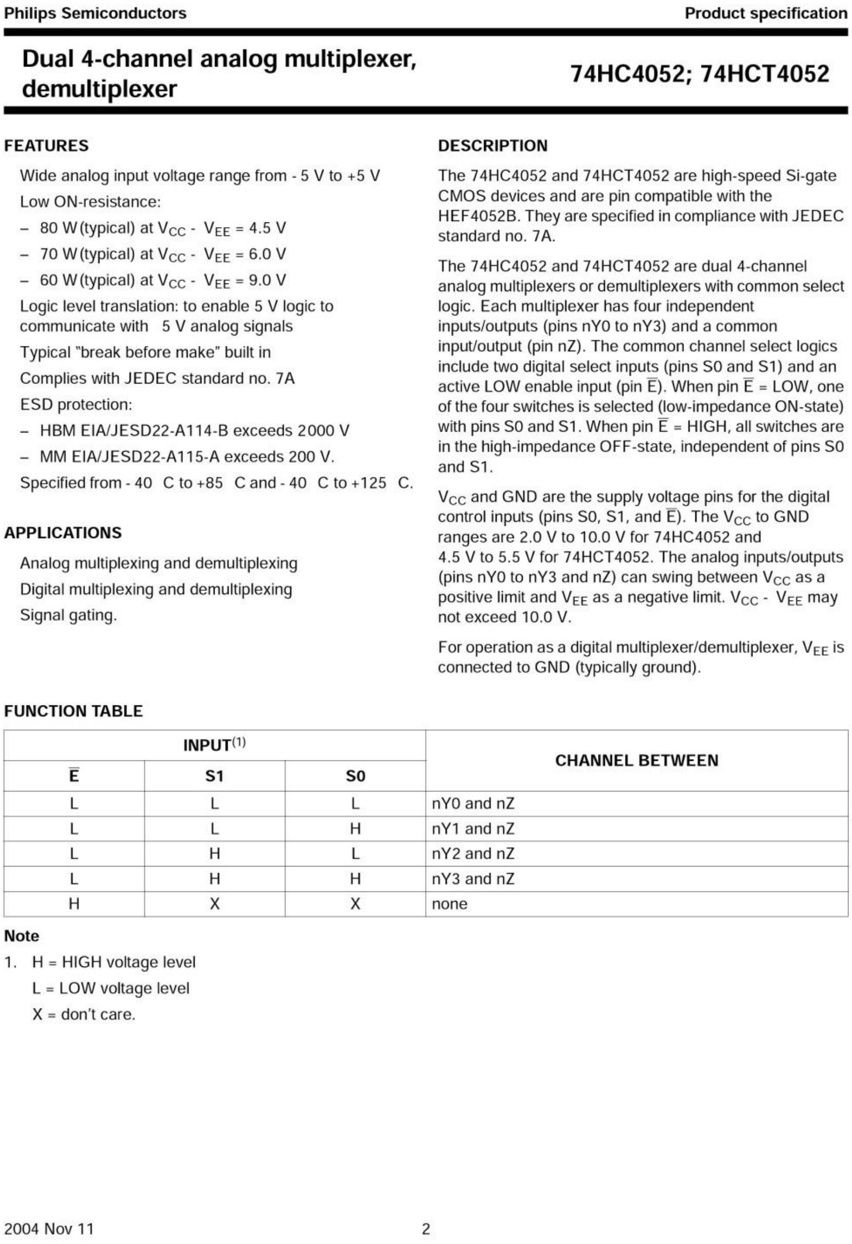
Supersedes data of 2003 May 16

Philips
Semiconductors

PHILIPS

APPENDIX B2

Datasheet of 74CH4052



Dual 4-channel analog multiplexer, demultiplexer

74HC4052; 74HCT4052

FEATURES

- Wide analog input voltage range from - 5 V to +5 V
- Low ON-resistance:
  - 80 W (typical) at V_{CC} - V_{EE} = 4.5 V
  - 70 W (typical) at V_{CC} - V_{EE} = 6.0 V
  - 60 W (typical) at V_{CC} - V_{EE} = 9.0 V
- Logic level translation: to enable 5 V logic to communicate with 5 V analog signals
- Typical "break before make" built in
- Complies with JEDEC standard no. 7A
- ESD protection:
  - HBM EIA/JESD22-A114-B exceeds 2000 V
  - MM EIA/JESD22-A115-A exceeds 200 V.
- Specified from - 40 C to +85 C and - 40 C to +125 C.

APPLICATIONS

- Analog multiplexing and demultiplexing
- Digital multiplexing and demultiplexing
- Signal gating.

DESCRIPTION

The 74HC4052 and 74HCT4052 are high-speed Si-gate CMOS devices and are pin compatible with the HEF4052B. They are specified in compliance with JEDEC standard no. 7A.

The 74HC4052 and 74HCT4052 are dual 4-channel analog multiplexers or demultiplexers with common select logic. Each multiplexer has four independent inputs/outputs (pins nY0 to nY3) and a common input/output (pin nZ). The common channel select logics include two digital select inputs (pins S0 and S1) and an active LOW enable input (pin $\overline{E}$). When pin $\overline{E}$ = LOW, one of the four switches is selected (low-impedance ON-state) with pins S0 and S1. When pin $\overline{E}$ = HIGH, all switches are in the high-impedance OFF-state, independent of pins S0 and S1.

V_{CC} and GND are the supply voltage pins for the digital control inputs (pins S0, S1, and $\overline{E}$). The V_{CC} to GND ranges are 2.0 V to 10.0 V for 74HC4052 and 4.5 V to 5.5 V for 74HCT4052. The analog inputs/outputs (pins nY0 to nY3 and nZ) can swing between V_{CC} as a positive limit and V_{EE} as a negative limit. V_{CC} - V_{EE} may not exceed 10.0 V.

For operation as a digital multiplexer/demultiplexer, V_{EE} is connected to GND (typically ground).

FUNCTION TABLE

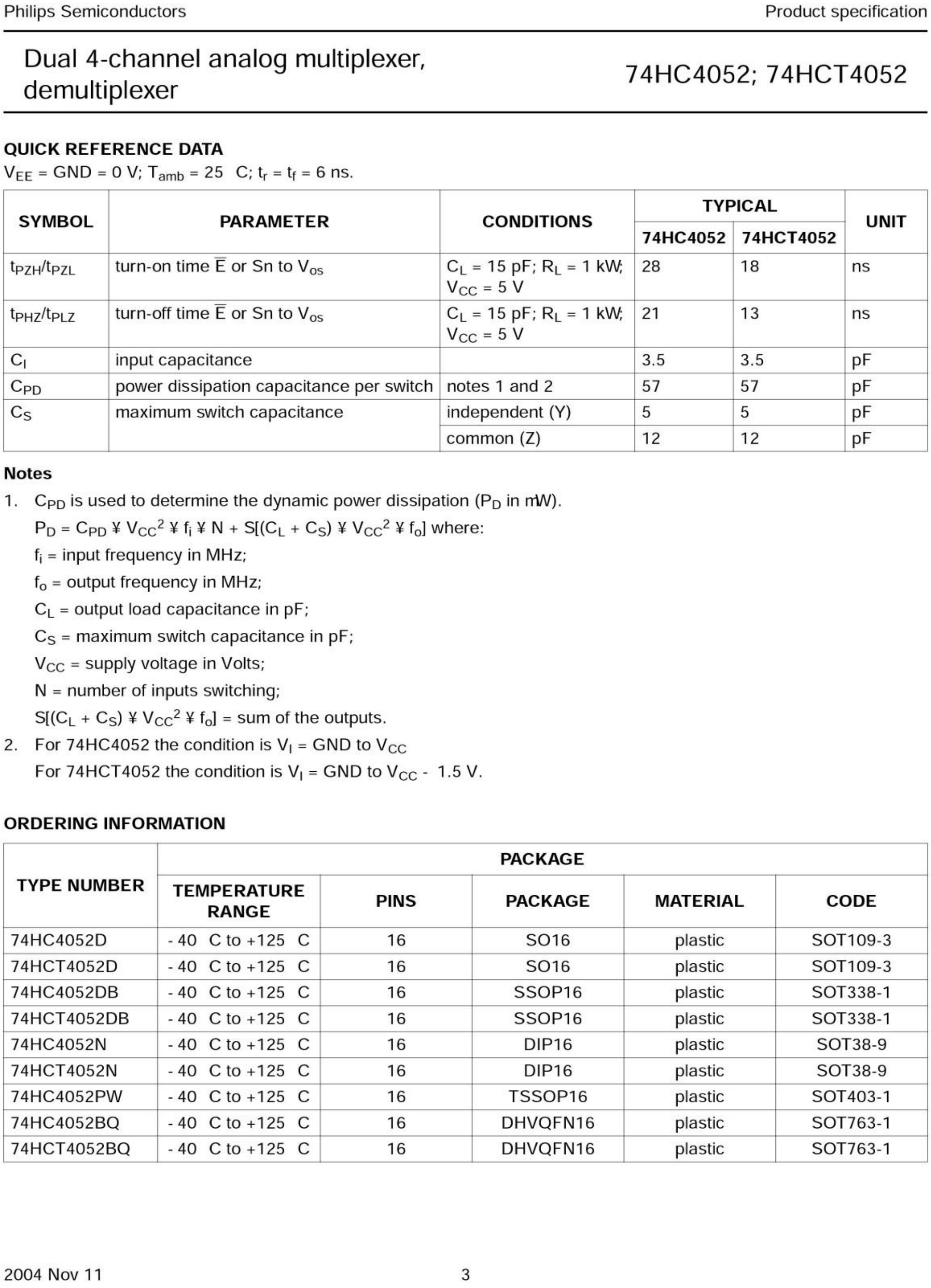
INPUT[1]			CHANNEL BETWEEN
$\overline{E}$	S1	S0	
L	L	L	nY0 and nZ
L	L	H	nY1 and nZ
L	H	L	nY2 and nZ
L	H	H	nY3 and nZ
H	X	X	none

Note

1. H = HIGH voltage level
   L = LOW voltage level
   X = don't care.

APPENDIX B3

Datasheet of 74CH4052



Philips Semiconductors Product specification

Dual 4-channel analog multiplexer, demultiplexer 74HC4052; 74HCT4052

QUICK REFERENCE DATA

V_{EE} = GND = 0 V; T_{amb} = 25 C; $t_r = t_f$ = 6 ns.

SYMBOL	PARAMETER	CONDITIONS	TYPICAL		UNIT
			74HC4052	74HCT4052	
t_{PZH}/t_{PZL}	turn-on time $\overline{E}$ or Sn to V_{os}	C_L = 15 pF; R_L = 1 kW; V_{CC} = 5 V	28	18	ns
t_{PHZ}/t_{PLZ}	turn-off time $\overline{E}$ or Sn to V_{os}	C_L = 15 pF; R_L = 1 kW; V_{CC} = 5 V	21	13	ns
C_I	input capacitance		3.5	3.5	pF
C_{PD}	power dissipation capacitance per switch	notes 1 and 2	57	57	pF
C_S	maximum switch capacitance	independent (Y)	5	5	pF
		common (Z)	12	12	pF

Notes

1. C_{PD} is used to determine the dynamic power dissipation (P_D in mW).
   $P_D = C_{PD}$ ¥ V_{CC}^2 ¥ f_i ¥ N + S[(C_L + C_S) ¥ V_{CC}^2 ¥ f_o] where:
   f_i = input frequency in MHz;
   f_o = output frequency in MHz;
   C_L = output load capacitance in pF;
   C_S = maximum switch capacitance in pF;
   V_{CC} = supply voltage in Volts;
   N = number of inputs switching;
   S[(C_L + C_S) ¥ V_{CC}^2 ¥ f_o] = sum of the outputs.
2. For 74HC4052 the condition is V_I = GND to V_{CC}
   For 74HCT4052 the condition is V_I = GND to V_{CC} - 1.5 V.

ORDERING INFORMATION

TYPE NUMBER	PACKAGE				
	TEMPERATURE RANGE	PINS	PACKAGE	MATERIAL	CODE
74HC4052D	- 40 C to +125 C	16	SO16	plastic	SOT109-3
74HCT4052D	- 40 C to +125 C	16	SO16	plastic	SOT109-3
74HC4052DB	- 40 C to +125 C	16	SSOP16	plastic	SOT338-1
74HCT4052DB	- 40 C to +125 C	16	SSOP16	plastic	SOT338-1
74HC4052N	- 40 C to +125 C	16	DIP16	plastic	SOT38-9
74HCT4052N	- 40 C to +125 C	16	DIP16	plastic	SOT38-9
74HC4052PW	- 40 C to +125 C	16	TSSOP16	plastic	SOT403-1
74HC4052BQ	- 40 C to +125 C	16	DHVQFN16	plastic	SOT763-1
74HCT4052BQ	- 40 C to +125 C	16	DHVQFN16	plastic	SOT763-1

2004 Nov 11 3

APPENDIX B4

Datasheet of 74CH4052

Dual 4-channel analog multiplexer, demultiplexer 74HC4052; 74HCT4052

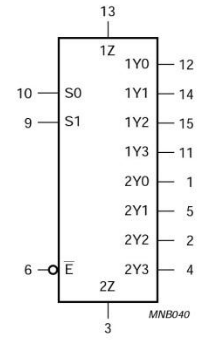


Fig.3 Logic symbol.

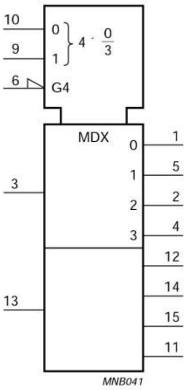


Fig.4 IEC logic symbol.

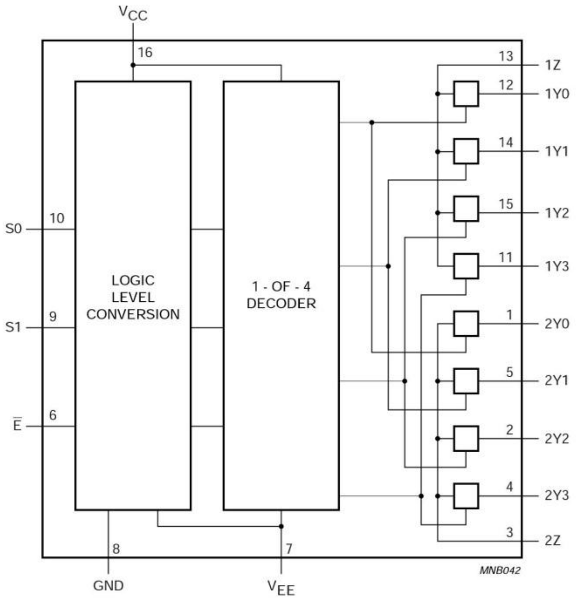
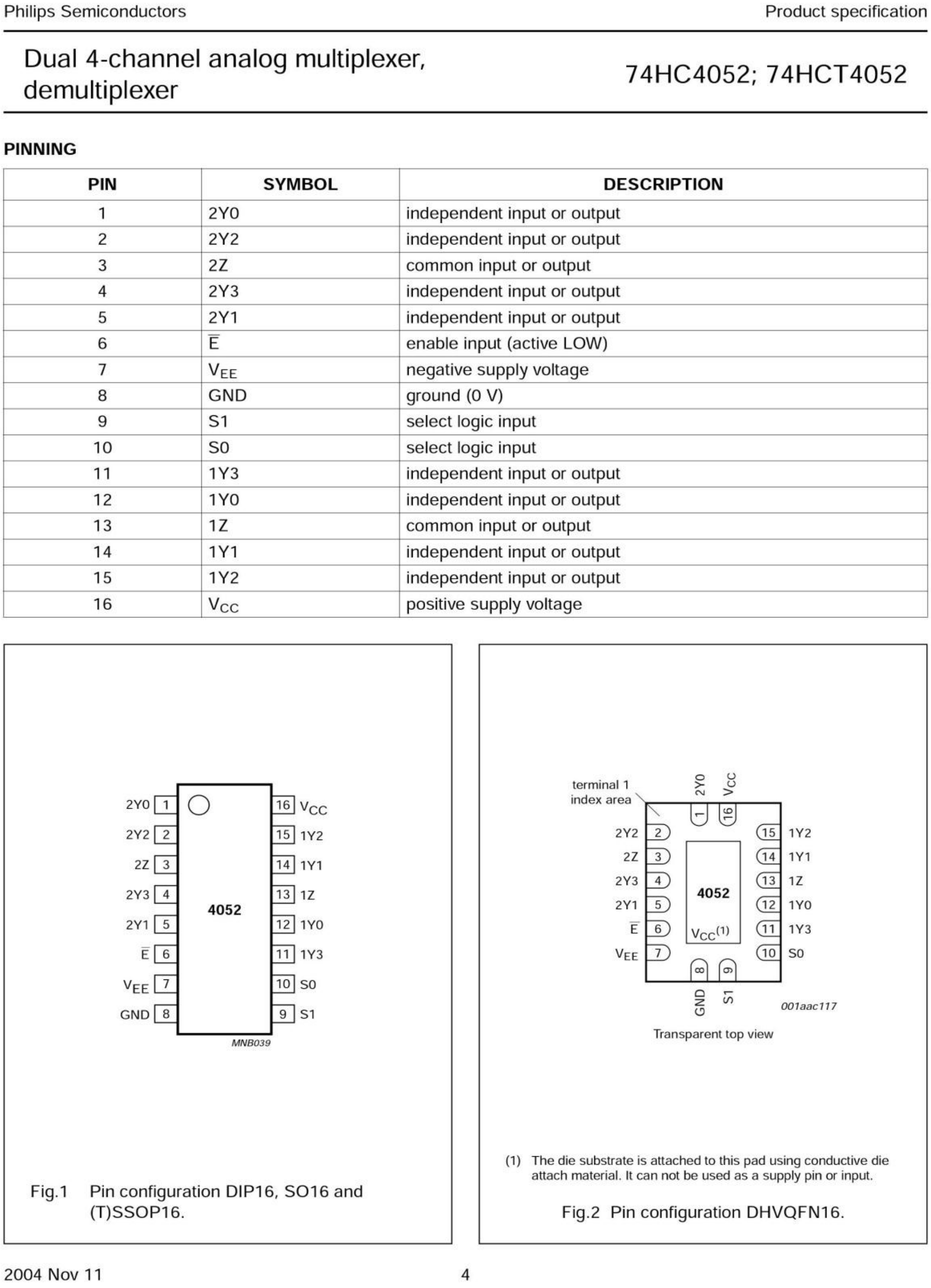


Fig.5 Functional diagram.

APPENDIX B5

Datasheet of 74CH4052



Dual 4-channel analog multiplexer, demultiplexer

74HC4052; 74HCT4052

PINNING

PIN	SYMBOL	DESCRIPTION
1	2Y0	independent input or output
2	2Y2	independent input or output
3	2Z	common input or output
4	2Y3	independent input or output
5	2Y1	independent input or output
6	$\overline{E}$	enable input (active LOW)
7	V_{EE}	negative supply voltage
8	GND	ground (0 V)
9	S1	select logic input
10	S0	select logic input
11	1Y3	independent input or output
12	1Y0	independent input or output
13	1Z	common input or output
14	1Y1	independent input or output
15	1Y2	independent input or output
16	V_{CC}	positive supply voltage

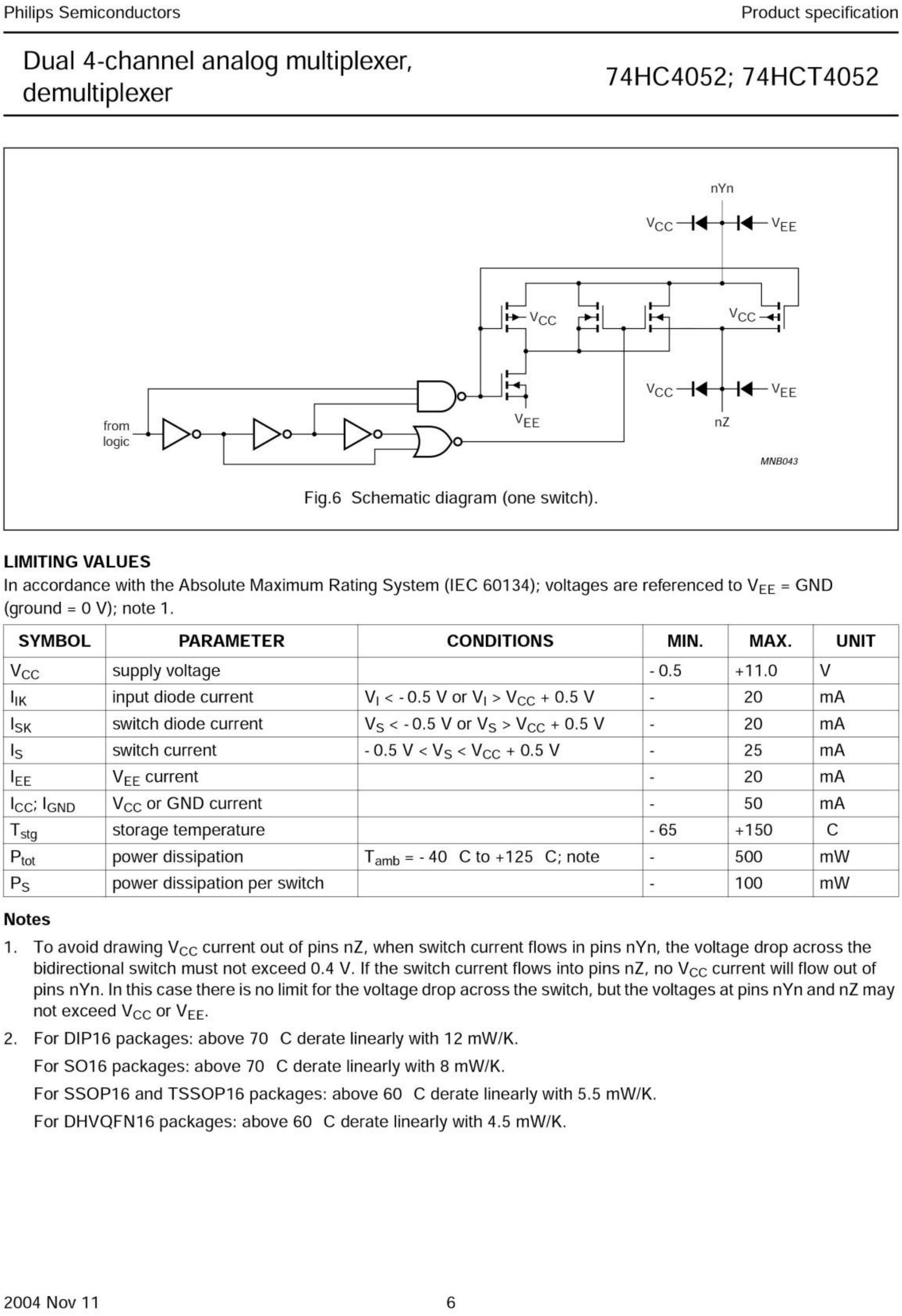
Fig.1 Pin configuration DIP16, SO16 and (T)SSOP16.

(1) The die substrate is attached to this pad using conductive die attach material. It can not be used as a supply pin or input.

Fig.2 Pin configuration DHVQFN16.

APPENDIX B6

Datasheet of 74CH4052



Dual 4-channel analog multiplexer, demultiplexer

74HC4052; 74HCT4052

Fig.6 Schematic diagram (one switch).

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 60134); voltages are referenced to V_{EE} = GND (ground = 0 V); note 1.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CC}	supply voltage		- 0.5	+11.0	V
I_{IK}	input diode current	$V_I < -0.5$ V or $V_I > V_{CC} + 0.5$ V	-	20	mA
I_{SK}	switch diode current	$V_S < -0.5$ V or $V_S > V_{CC} + 0.5$ V	-	20	mA
I_S	switch current	$-0.5 \text{ V} < V_S < V_{CC} + 0.5$ V	-	25	mA
I_{EE}	V_{EE} current		-	20	mA
I_{CC}; I_{GND}	V_{CC} or GND current		-	50	mA
T_{stg}	storage temperature		- 65	+150	C
P_{tot}	power dissipation	T_{amb} = - 40 C to +125 C; note	-	500	mW
P_S	power dissipation per switch		-	100	mW

Notes

1. To avoid drawing V_{CC} current out of pins nZ, when switch current flows in pins nYn, the voltage drop across the bidirectional switch must not exceed 0.4 V. If the switch current flows into pins nZ, no V_{CC} current will flow out of pins nYn. In this case there is no limit for the voltage drop across the switch, but the voltages at pins nYn and nZ may not exceed V_{CC} or V_{EE}.
2. For DIP16 packages: above 70 C derate linearly with 12 mW/K.

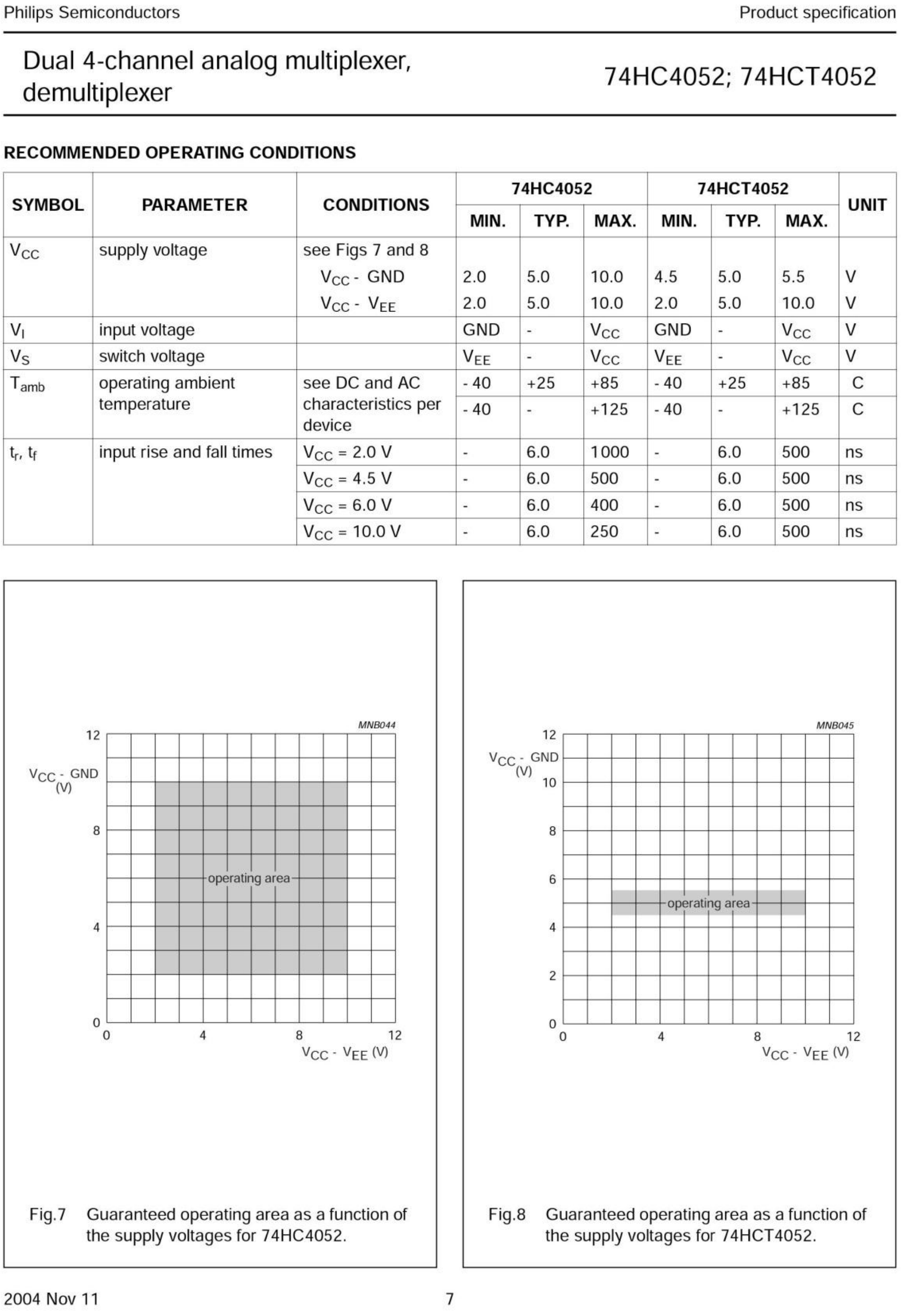
   For SO16 packages: above 70 C derate linearly with 8 mW/K.

   For SSOP16 and TSSOP16 packages: above 60 C derate linearly with 5.5 mW/K.

   For DHVQFN16 packages: above 60 C derate linearly with 4.5 mW/K.

APPENDIX B6

Datasheet of 74CH4052



Philips Semiconductors | Product specification

Dual 4-channel analog multiplexer, demultiplexer — **74HC4052; 74HCT4052**

RECOMMENDED OPERATING CONDITIONS

SYMBOL	PARAMETER	CONDITIONS	74HC4052 MIN.	74HC4052 TYP.	74HC4052 MAX.	74HCT4052 MIN.	74HCT4052 TYP.	74HCT4052 MAX.	UNIT
V_{CC}	supply voltage	see Figs 7 and 8							
		V_{CC} - GND	2.0	5.0	10.0	4.5	5.0	5.5	V
		V_{CC} - V_{EE}	2.0	5.0	10.0	2.0	5.0	10.0	V
V_I	input voltage		GND	-	V_{CC}	GND	-	V_{CC}	V
V_S	switch voltage		V_{EE}	-	V_{CC}	V_{EE}	-	V_{CC}	V
T_{amb}	operating ambient temperature	see DC and AC characteristics per device	- 40	+25	+85	- 40	+25	+85	C
			- 40	-	+125	- 40	-	+125	C
t_r, t_f	input rise and fall times	V_{CC} = 2.0 V	-	6.0	1000	-	6.0	500	ns
		V_{CC} = 4.5 V	-	6.0	500	-	6.0	500	ns
		V_{CC} = 6.0 V	-	6.0	400	-	6.0	500	ns
		V_{CC} = 10.0 V	-	6.0	250	-	6.0	500	ns

Fig.7 Guaranteed operating area as a function of the supply voltages for 74HC4052.

Fig.8 Guaranteed operating area as a function of the supply voltages for 74HCT4052.

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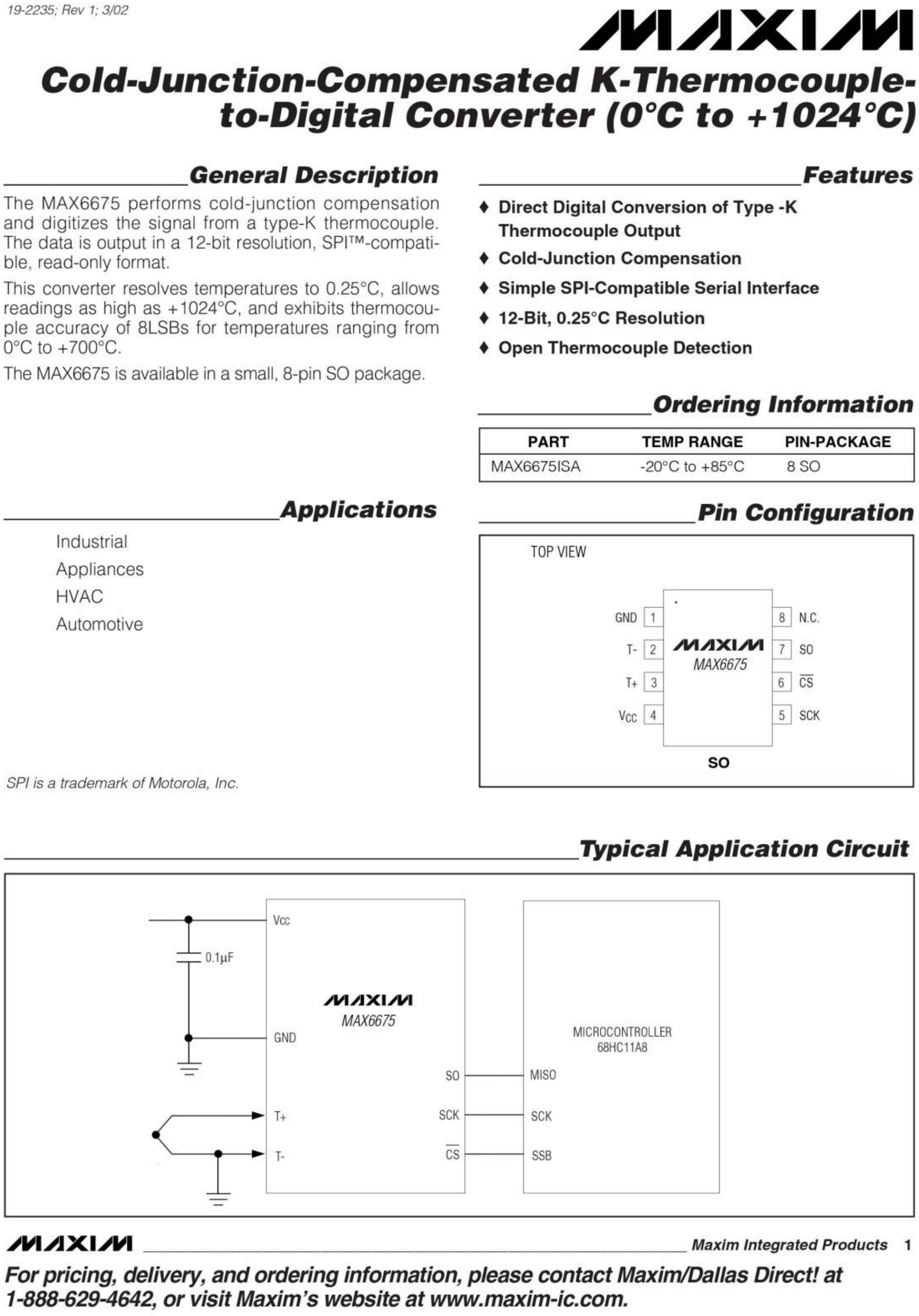
APPENDIX C1

Datasheet of MAX6675



19-2235; Rev 1; 3/02

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

MAX6675

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

Typical Application Circuit

Maxim Integrated Products 1

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

APPENDIX C2

Datasheet of MAX6675

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

MAX6675

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.

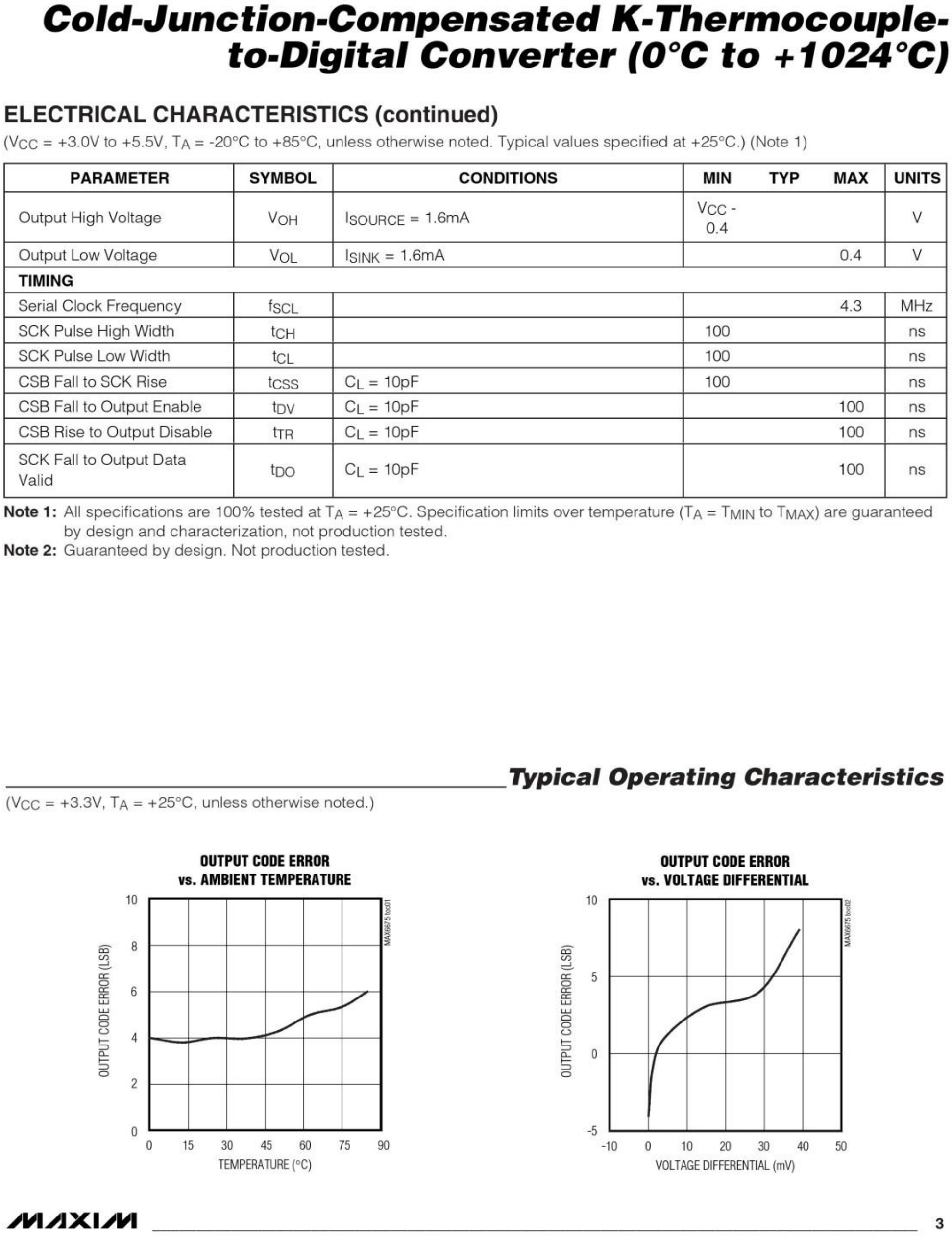
ELECTRICAL CHARACTERISTICS

(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

APPENDIX C3

Datasheet of MAX6675



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

MAX6675

ELECTRICAL CHARACTERISTICS (continued)

(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
Output High Voltage	V_{OH}	I_{SOURCE} = 1.6mA	V_{CC} - 0.4			V
Output Low Voltage	V_{OL}	I_{SINK} = 1.6mA			0.4	V
TIMING						
Serial Clock Frequency	f_{SCL}				4.3	MHz
SCK Pulse High Width	t_{CH}		100			ns
SCK Pulse Low Width	t_{CL}		100			ns
CSB Fall to SCK Rise	t_{CSS}	C_L = 10pF	100			ns
CSB Fall to Output Enable	t_{DV}	C_L = 10pF			100	ns
CSB Rise to Output Disable	t_{TR}	C_L = 10pF			100	ns
SCK Fall to Output Data Valid	t_{DO}	C_L = 10pF			100	ns

Note 1: All specifications are 100% tested at T_A = +25°C. Specification limits over temperature (T_A = T_{MIN} to T_{MAX}) are guaranteed by design and characterization, not production tested.

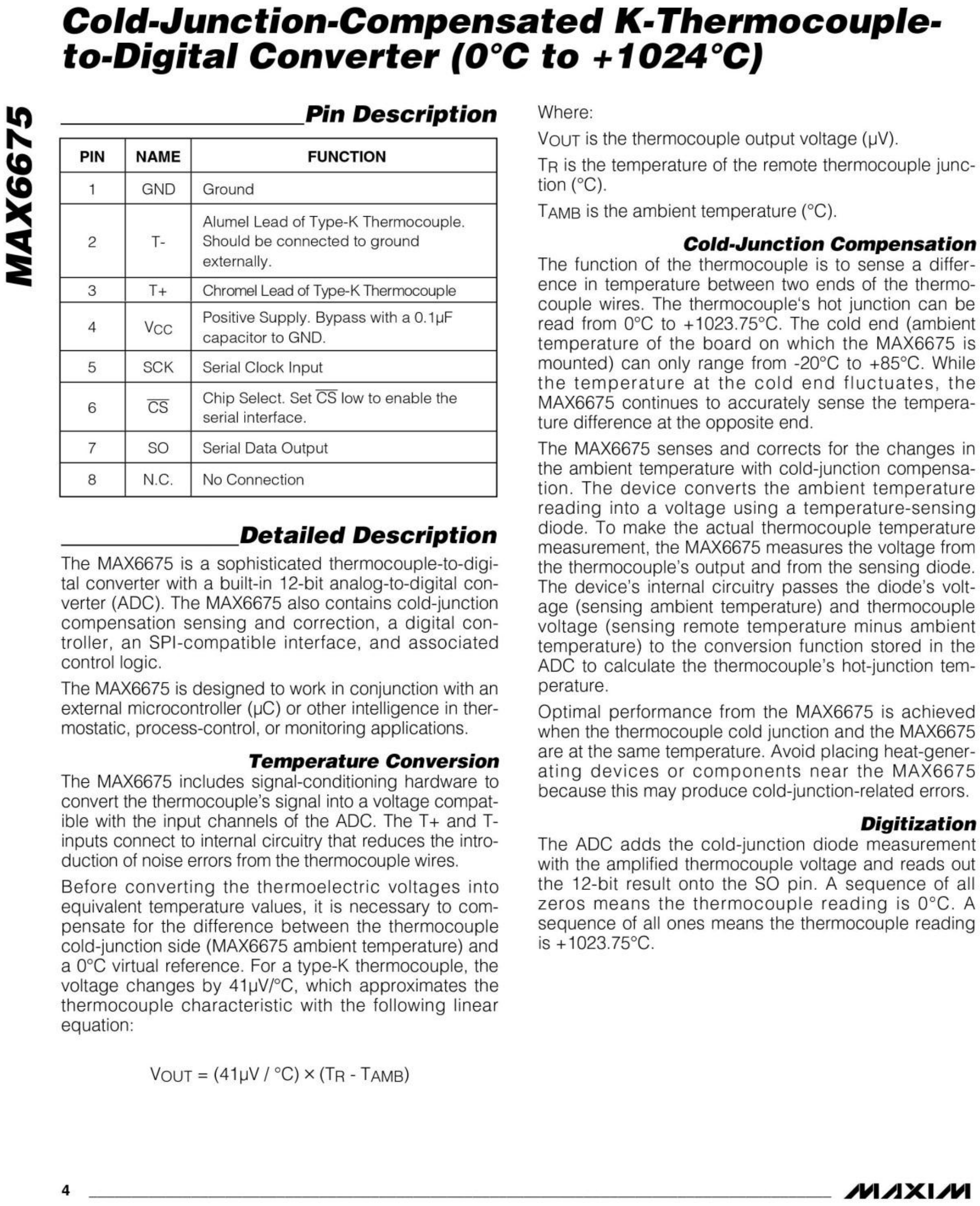
Note 2: Guaranteed by design. Not production tested.

Typical Operating Characteristics

(V_{CC} = +3.3V, T_A = +25°C, unless otherwise noted.)

APPENDIX C4

Datasheet of MAX6675



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

MAX6675

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.

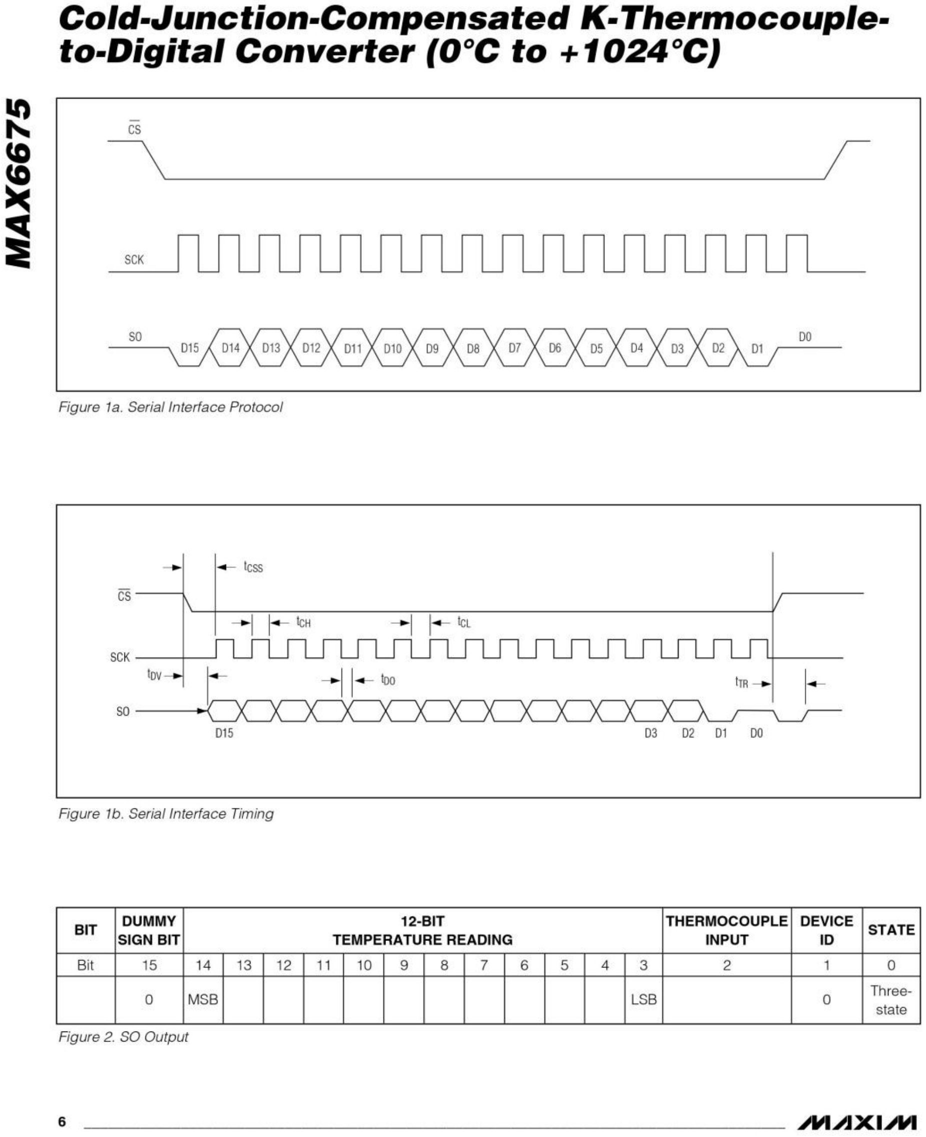
Optimal performance from the MAX6675 is achieved when the thermocouple cold junction and the MAX6675 are at the same temperature. Avoid placing heat-generating devices or components near the MAX6675 because this may produce cold-junction-related errors.

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.

APPENDIX C5

Datasheet of MAX6675



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

MAX6675

Figure 1a. Serial Interface Protocol

Figure 1b. Serial Interface Timing

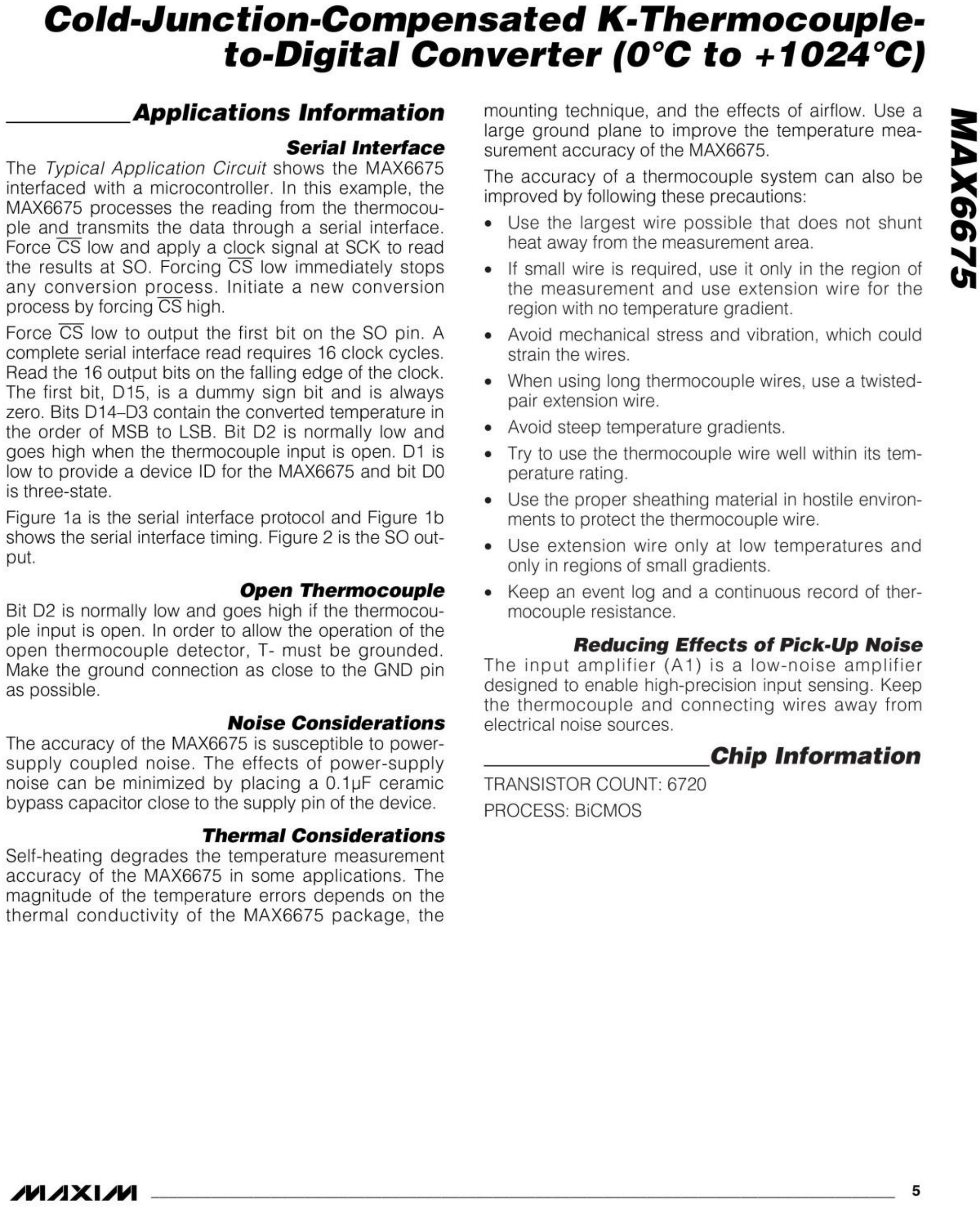
BIT	DUMMY SIGN BIT	12-BIT TEMPERATURE READING												THERMOCOUPLE INPUT	DEVICE ID	STATE
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0	MSB											LSB		0	Three-state

Figure 2. SO Output

6 MAXIM

APPENDIX C6

Datasheet of MAX6675



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

MAX6675

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

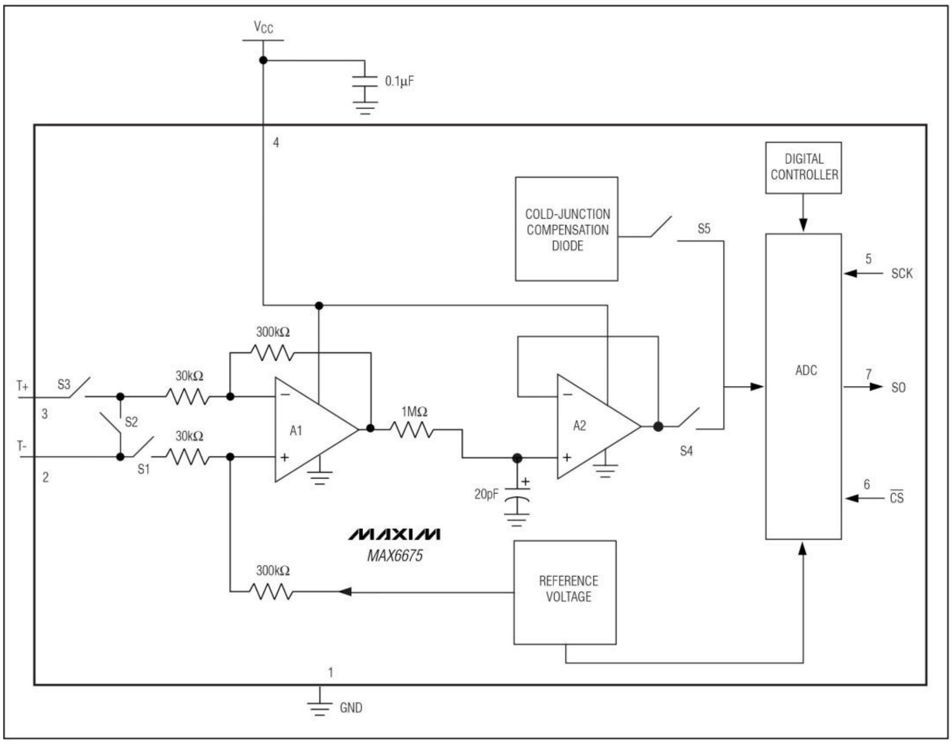
PROCESS: BiCMOS

APPENDIX C7

Datasheet of MAX6675

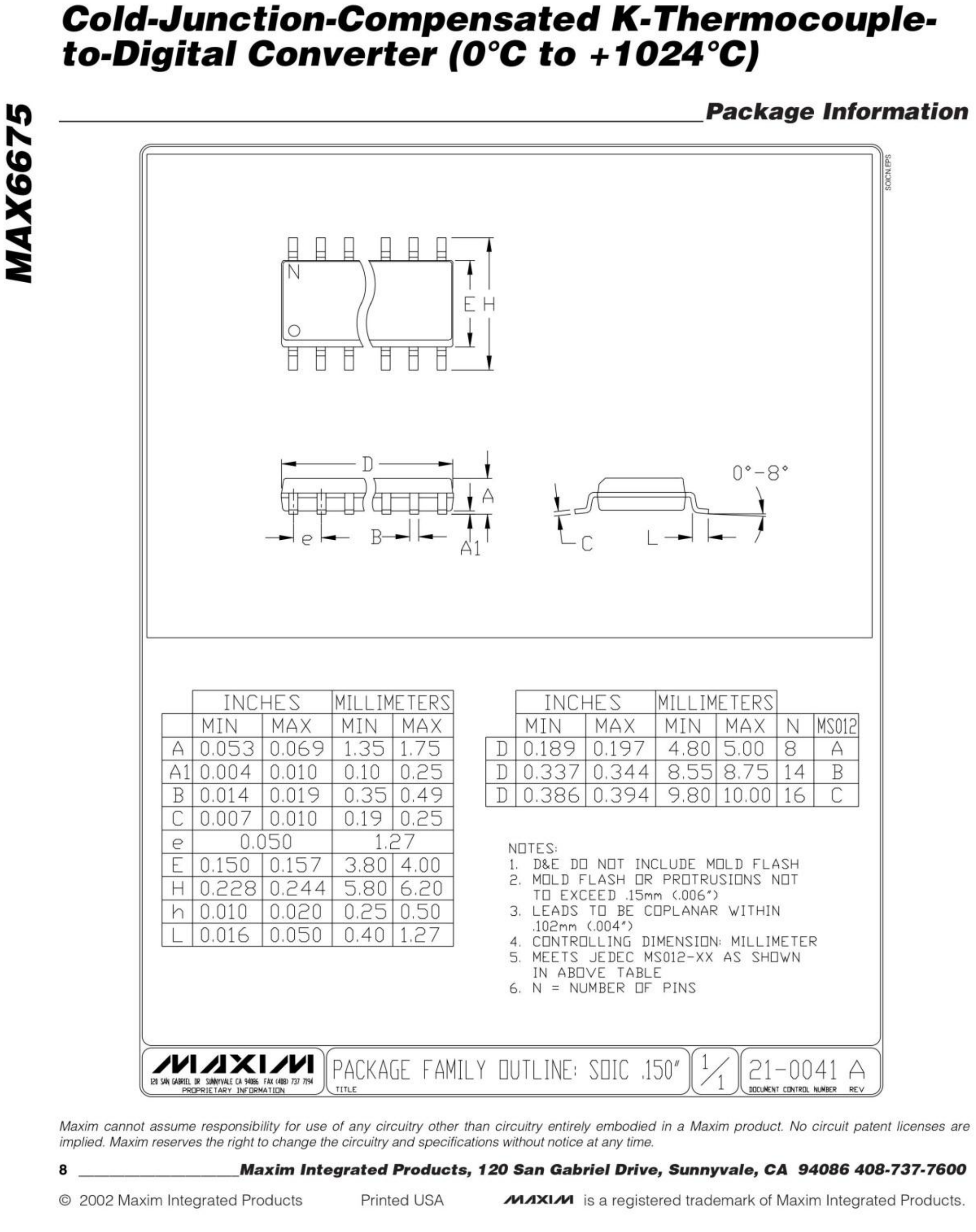
Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

Block Diagram



APPENDIX C8

Datasheet of MAX6675



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

MAX6675

Package Information

	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050		1.27	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
h	0.010	0.020	0.25	0.50
L	0.016	0.050	0.40	1.27

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	A
D	0.337	0.344	8.55	8.75	14	B
D	0.386	0.394	9.80	10.00	16	C

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. LEADS TO BE COPLANAR WITHIN .102mm (.004")
4. CONTROLLING DIMENSION: MILLIMETER
5. MEETS JEDEC MS012-XX AS SHOWN IN ABOVE TABLE
6. N = NUMBER OF PINS

MAXIM
121 SAN GABRIEL DR. SUNNYVALE CA 94086 FAX (408) 737 7194
PROPRIETARY INFORMATION

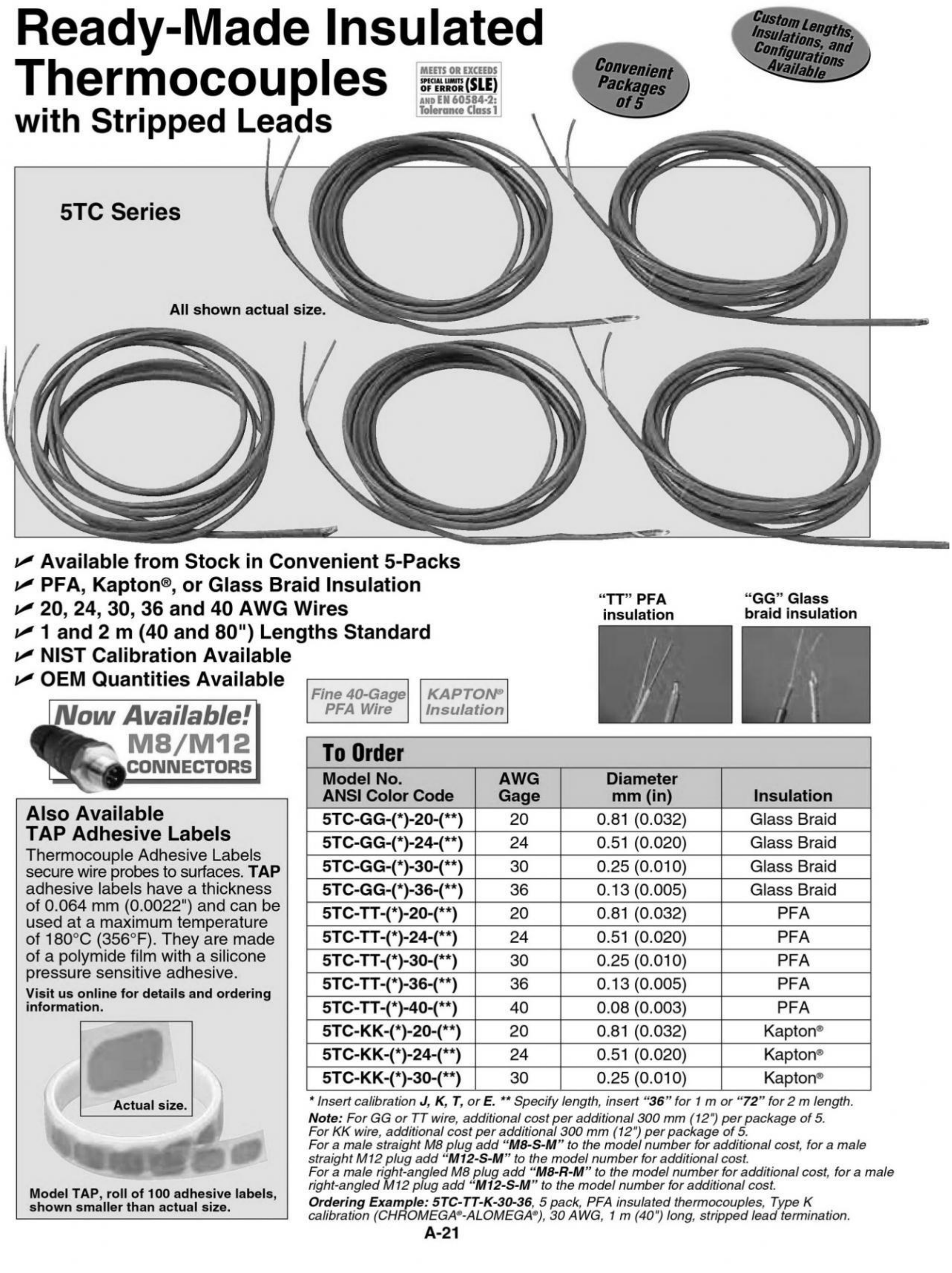
TITLE
PACKAGE FAMILY OUTLINE: SOIC .150"

1/1

21-0041 A
DOCUMENT CONTROL NUMBER REV

APPENDIX D1

5TC series specification



Ready-Made Insulated Thermocouples

with Stripped Leads

MEETS OR EXCEEDS SPECIAL LIMITS OF ERROR (SLE) AND EN 60584-2: Tolerance Class 1

Convenient Packages of 5

Custom Lengths, Insulations, and Configurations Available

5TC Series

All shown actual size.

- Available from Stock in Convenient 5-Packs
- PFA, Kapton®, or Glass Braid Insulation
- 20, 24, 30, 36 and 40 AWG Wires
- 1 and 2 m (40 and 80") Lengths Standard
- NIST Calibration Available
- OEM Quantities Available

Now Available! M8/M12 CONNECTORS

Fine 40-Gage PFA Wire

KAPTON® Insulation

"TT" PFA insulation

"GG" Glass braid insulation

To Order

Model No. ANSI Color Code	AWG Gage	Diameter mm (in)	Insulation
5TC-GG-(*)-20-(**)	20	0.81 (0.032)	Glass Braid
5TC-GG-(*)-24-(**)	24	0.51 (0.020)	Glass Braid
5TC-GG-(*)-30-(**)	30	0.25 (0.010)	Glass Braid
5TC-GG-(*)-36-(**)	36	0.13 (0.005)	Glass Braid
5TC-TT-(*)-20-(**)	20	0.81 (0.032)	PFA
5TC-TT-(*)-24-(**)	24	0.51 (0.020)	PFA
5TC-TT-(*)-30-(**)	30	0.25 (0.010)	PFA
5TC-TT-(*)-36-(**)	36	0.13 (0.005)	PFA
5TC-TT-(*)-40-(**)	40	0.08 (0.003)	PFA
5TC-KK-(*)-20-(**)	20	0.81 (0.032)	Kapton®
5TC-KK-(*)-24-(**)	24	0.51 (0.020)	Kapton®
5TC-KK-(*)-30-(**)	30	0.25 (0.010)	Kapton®

** Insert calibration **J, K, T,** or **E.** ** Specify length, insert **"36"** for 1 m or **"72"** for 2 m length.*

***Note:** For GG or TT wire, additional cost per additional 300 mm (12") per package of 5.
For KK wire, additional cost per additional 300 mm (12") per package of 5.
For a male straight M8 plug add **"M8-S-M"** to the model number for additional cost, for a male straight M12 plug add **"M12-S-M"** to the model number for additional cost.
For a male right-angled M8 plug add **"M8-R-M"** to the model number for additional cost, for a male right-angled M12 plug add **"M12-S-M"** to the model number for additional cost.*

***Ordering Example: 5TC-TT-K-30-36**, 5 pack, PFA insulated thermocouples, Type K calibration (CHROMEGA®-ALOMEGA®), 30 AWG, 1 m (40") long, stripped lead termination.*

Also Available
TAP Adhesive Labels

Thermocouple Adhesive Labels secure wire probes to surfaces. **TAP** adhesive labels have a thickness of 0.064 mm (0.0022") and can be used at a maximum temperature of 180°C (356°F). They are made of a polymide film with a silicone pressure sensitive adhesive.

Visit us online for details and ordering information.

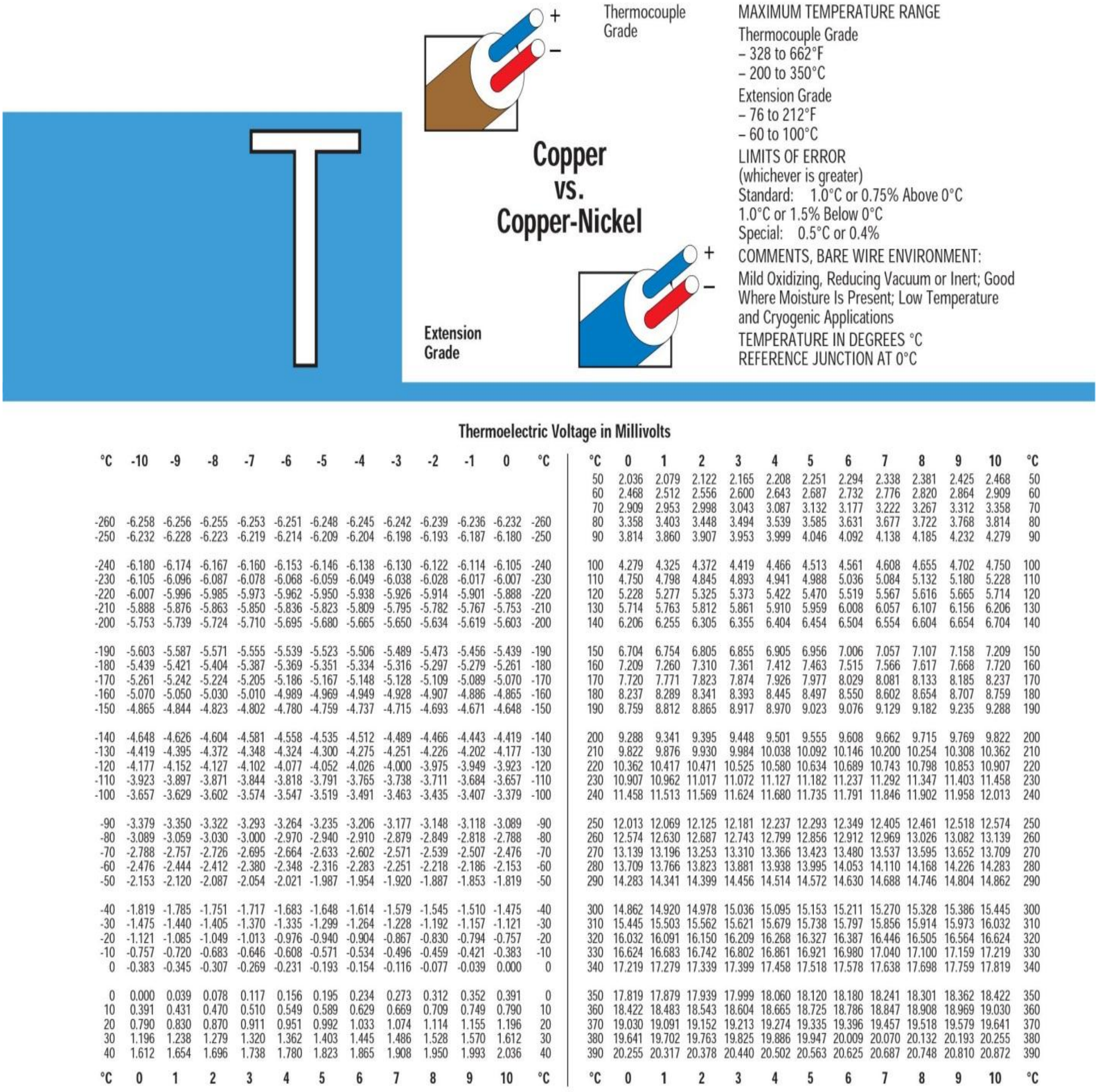
Actual size.

Model TAP, roll of 100 adhesive labels, shown smaller than actual size.

A-21

APPENDIX E1

T-Type Thermocouple Reference Tables



MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
– 328 to 662°F
– 200 to 350°C
Extension Grade
– 76 to 212°F
– 60 to 100°C

LIMITS OF ERROR
(whichever is greater)
Standard: 1.0°C or 0.75% Above 0°C
1.0°C or 1.5% Below 0°C
Special: 0.5°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:
Mild Oxidizing, Reducing Vacuum or Inert; Good Where Moisture Is Present; Low Temperature and Cryogenic Applications

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.258	-6.256	-6.255	-6.253	-6.251	-6.248	-6.245	-6.242	-6.239	-6.236	-6.232	-260
-250	-6.232	-6.228	-6.223	-6.219	-6.214	-6.209	-6.204	-6.198	-6.193	-6.187	-6.180	-250
-240	-6.180	-6.174	-6.167	-6.160	-6.153	-6.146	-6.138	-6.130	-6.122	-6.114	-6.105	-240
-230	-6.105	-6.096	-6.087	-6.078	-6.068	-6.059	-6.049	-6.038	-6.028	-6.017	-6.007	-230
-220	-6.007	-5.996	-5.985	-5.973	-5.962	-5.950	-5.938	-5.926	-5.914	-5.901	-5.888	-220
-210	-5.888	-5.876	-5.863	-5.850	-5.836	-5.823	-5.809	-5.795	-5.782	-5.767	-5.753	-210
-200	-5.753	-5.739	-5.724	-5.710	-5.695	-5.680	-5.665	-5.650	-5.634	-5.619	-5.603	-200
-190	-5.603	-5.587	-5.571	-5.555	-5.539	-5.523	-5.506	-5.489	-5.473	-5.456	-5.439	-190
-180	-5.439	-5.421	-5.404	-5.387	-5.369	-5.351	-5.334	-5.316	-5.297	-5.279	-5.261	-180
-170	-5.261	-5.242	-5.224	-5.205	-5.186	-5.167	-5.148	-5.128	-5.109	-5.089	-5.070	-170
-160	-5.070	-5.050	-5.030	-5.010	-4.989	-4.969	-4.949	-4.928	-4.907	-4.886	-4.865	-160
-150	-4.865	-4.844	-4.823	-4.802	-4.780	-4.759	-4.737	-4.715	-4.693	-4.671	-4.648	-150
-140	-4.648	-4.626	-4.604	-4.581	-4.558	-4.535	-4.512	-4.489	-4.466	-4.443	-4.419	-140
-130	-4.419	-4.395	-4.372	-4.348	-4.324	-4.300	-4.275	-4.251	-4.226	-4.202	-4.177	-130
-120	-4.177	-4.152	-4.127	-4.102	-4.077	-4.052	-4.026	-4.000	-3.975	-3.949	-3.923	-120
-110	-3.923	-3.897	-3.871	-3.844	-3.818	-3.791	-3.765	-3.738	-3.711	-3.684	-3.657	-110
-100	-3.657	-3.629	-3.602	-3.574	-3.547	-3.519	-3.491	-3.463	-3.435	-3.407	-3.379	-100
-90	-3.379	-3.350	-3.322	-3.293	-3.264	-3.235	-3.206	-3.177	-3.148	-3.118	-3.089	-90
-80	-3.089	-3.059	-3.030	-3.000	-2.970	-2.940	-2.910	-2.879	-2.849	-2.818	-2.788	-80
-70	-2.788	-2.757	-2.726	-2.695	-2.664	-2.633	-2.602	-2.571	-2.539	-2.507	-2.476	-70
-60	-2.476	-2.444	-2.412	-2.380	-2.348	-2.316	-2.283	-2.251	-2.218	-2.186	-2.153	-60
-50	-2.153	-2.120	-2.087	-2.054	-2.021	-1.987	-1.954	-1.920	-1.887	-1.853	-1.819	-50
-40	-1.819	-1.785	-1.751	-1.717	-1.683	-1.648	-1.614	-1.579	-1.545	-1.510	-1.475	-40
-30	-1.475	-1.440	-1.405	-1.370	-1.335	-1.299	-1.264	-1.228	-1.192	-1.157	-1.121	-30
-20	-1.121	-1.085	-1.049	-1.013	-0.976	-0.940	-0.904	-0.867	-0.830	-0.794	-0.757	-20
-10	-0.757	-0.720	-0.683	-0.646	-0.608	-0.571	-0.534	-0.496	-0.459	-0.421	-0.383	-10
0	-0.383	-0.345	-0.307	-0.269	-0.231	-0.193	-0.154	-0.116	-0.077	-0.039	0.000	0

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352	0.391	0
10	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.790	10
20	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155	1.196	20
30	1.196	1.238	1.279	1.320	1.362	1.403	1.445	1.486	1.528	1.570	1.612	30
40	1.612	1.654	1.696	1.738	1.780	1.823	1.865	1.908	1.950	1.993	2.036	40

°C	0	1	2	3	4	5	6	7	8	9	10	°C
50	2.036	2.079	2.122	2.165	2.208	2.251	2.294	2.338	2.381	2.425	2.468	50
60	2.468	2.512	2.556	2.600	2.643	2.687	2.732	2.776	2.820	2.864	2.909	60
70	2.909	2.953	2.998	3.043	3.087	3.132	3.177	3.222	3.267	3.312	3.358	70
80	3.358	3.403	3.448	3.494	3.539	3.585	3.631	3.677	3.722	3.768	3.814	80
90	3.814	3.860	3.907	3.953	3.999	4.046	4.092	4.138	4.185	4.232	4.279	90
100	4.279	4.325	4.372	4.419	4.466	4.513	4.561	4.608	4.655	4.702	4.750	100
110	4.750	4.798	4.845	4.893	4.941	4.988	5.036	5.084	5.132	5.180	5.228	110
120	5.228	5.277	5.325	5.373	5.422	5.470	5.519	5.567	5.616	5.665	5.714	120
130	5.714	5.763	5.812	5.861	5.910	5.959	6.008	6.057	6.107	6.156	6.206	130
140	6.206	6.255	6.305	6.355	6.404	6.454	6.504	6.554	6.604	6.654	6.704	140
150	6.704	6.754	6.805	6.855	6.905	6.956	7.006	7.057	7.107	7.158	7.209	150
160	7.209	7.260	7.310	7.361	7.412	7.463	7.515	7.566	7.617	7.668	7.720	160
170	7.720	7.771	7.823	7.874	7.926	7.977	8.029	8.081	8.133	8.185	8.237	170
180	8.237	8.289	8.341	8.393	8.445	8.497	8.550	8.602	8.654	8.707	8.759	180
190	8.759	8.812	8.865	8.917	8.970	9.023	9.076	9.129	9.182	9.235	9.288	190
200	9.288	9.341	9.395	9.448	9.501	9.555	9.608	9.662	9.715	9.769	9.822	200
210	9.822	9.876	9.930	9.984	10.038	10.092	10.146	10.200	10.254	10.308	10.362	210
220	10.362	10.417	10.471	10.525	10.580	10.634	10.689	10.743	10.798	10.853	10.907	220
230	10.907	10.962	11.017	11.072	11.127	11.182	11.237	11.292	11.347	11.403	11.458	230
240	11.458	11.513	11.569	11.624	11.680	11.735	11.791	11.846	11.902	11.958	12.013	240
250	12.013	12.069	12.125	12.181	12.237	12.293	12.349	12.405	12.461	12.518	12.574	250
260	12.574	12.630	12.687	12.743	12.799	12.856	12.912	12.969	13.026	13.082	13.139	260
270	13.139	13.196	13.253	13.310	13.366	13.423	13.480	13.537	13.595	13.652	13.709	270
280	13.709	13.766	13.823	13.881	13.938	13.995	14.053	14.110	14.168	14.226	14.283	280
290	14.283	14.341	14.399	14.456	14.514	14.572	14.630	14.688	14.746	14.804	14.862	290
300	14.862	14.920	14.978	15.036	15.095	15.153	15.211	15.270	15.328	15.386	15.445	300
310	15.445	15.503	15.562	15.621	15.679	15.738	15.797	15.856	15.914	15.973	16.032	310
320	16.032	16.091	16.150	16.209	16.268	16.327	16.387	16.446	16.505	16.564	16.624	320
330	16.624	16.683	16.742	16.802	16.861	16.921	16.980	17.040	17.100	17.159	17.219	330
340	17.219	17.279	17.339	17.399	17.458	17.518	17.578	17.638	17.698	17.759	17.819	340
350	17.819	17.879	17.939	17.999	18.060	18.120	18.180	18.241	18.301	18.362	18.422	350
360	18.422	18.483	18.543	18.604	18.665	18.725	18.786	18.847	18.908	18.969	19.030	360
370	19.030	19.091	19.152	19.213	19.274	19.335	19.396	19.457	19.518	19.579	19.641	370
380	19.641	19.702	19.763	19.825	19.886	19.947	20.009	20.070	20.132	20.193	20.255	380
390	20.255	20.317	20.378	20.440	20.502	20.563	20.625	20.687	20.748	20.810	20.872	390

APPENDIX F1

Frimware cooding: main.ino

```
// This #include statement was automatically added by the Spark IDE.
#include "math.h"
#include "max6675.h"//hardware libraries for max6675 breakout board and phant
config.

int thermoDO = D3; //initialized data pin to D3
int thermoCS = D4; //communicate chip select pin to D2
int thermoCLK = D2; //communicate clock pin to D2
int state = 0;//led toogle data memory

MAX6675 thermocouple(thermoCLK, thermoCS, thermoDO);//Create thermocouple
object
const char server[] = "data.sparkfun.com"; // Phant server location
const char publicKey[] = "bG5GK8gZ08fWOo1NXqZX"; // Public key from phant
server
const char privateKey[] = "Vpep291Bq9CpBbYEaNGa"; // Private key from phant
server
Phant phant(server, publicKey, privateKey);// Create a object name phant

const int POST_RATE = 1000; // Time between posts, in ms.
unsigned long lastPost = 0;//To keep track of last post time
double temp[4];  //array to store data from different multiplexer
void setup() {
    pinMode(D0, OUTPUT);digitalWrite(D0, HIGH); //D0 as VCC pin
    pinMode(D1, OUTPUT);digitalWrite(D1, LOW);// D1 as ground pin
    pinMode(D5, OUTPUT);//multiplexer selector input 1
    pinMode(D6, OUTPUT);//multiplexer selector input 2
    pinMode(D7, OUTPUT);//led indicator
  Serial.begin(9600);
}

void loop() {

   digitalWrite(D5, LOW);
   digitalWrite(D6, LOW);//switch to channel 1
   temp[0]=thermocouple.readCelsius()-15;//store temperature in temp[0]
   delay(200);
   digitalWrite(D5, LOW);
   digitalWrite(D6, HIGH); //switch to channel 2
   temp[1]=thermocouple.readCelsius()-15; ;//store temperature in temp[1]
   delay(200);
   digitalWrite(D5, HIGH);
   digitalWrite(D6, LOW); //switch to channel 3
   temp[2]=thermocouple.readCelsius()-15; ;//store temperature in temp[2]
```

```
   delay(200);
   digitalWrite(D5, HIGH);
   digitalWrite(D6, HIGH); //switch to channel 4
   temp[3]=thermocouple.readCelsius()-15;//store temperature in temp[4]
   delay(200);

         // If it's been POST_RATE 1000ms, try to post again.
   if (lastPost + POST_RATE < millis())
   { // If the post succeeds, update lastPost value
          if (postToPhant() > 0)
      {
         lastPost = millis();
      }
                  // If the post fails, delay 50ms and try again.
   }
         delay(50);
}

int postToPhant()
{
   phant.add("tc1", temp[0]);
   phant.add("tc2", temp[1]);
   phant.add("tc3", temp[2]);
   phant.add("tc4", temp[3]);

   TCPClient client;
   char response[512];
   int i = 0;
   int retVal = 0;

   if (client.connect(server, 80)) // Connect to the server
   {
      client.print(phant.post());//Check the server responds
      delay(1000);
.
      while (client.available())
      {
         char c = client.read();
         Serial.print(c); // Print the response
         if (i < 512)
            response[i++] = c; // Add character to response string
      }
         // find respond status
      if (strstr(response, "200 OK"))
      {
         digitalWrite(D7, (state) ? HIGH : LOW);
         state = !state; //Toggle led when data is transmitted
         retVal = 1;//set retVal to 1 when post success
      }
```

```
        else if (strstr(response, "400 Bad Request"))
        {
            retVal = -1; ;//set retVal to -1 when bad request
        }
        else
        {
            retVal = -2; //set retVal to -2 when receive undefined responds
        }
    }
    else
    {
        retVal = -3; //set retVal to -3 when connection fail.
    }
    client.stop();//Stop the connection.
    return retVal;// Return value of retVal
}
```

APPENDIX F2

Frimware cooding: max6675.cpp

```
#include "math.h"
#include <stdlib.h>
#include "max6675.h"

MAX6675::MAX6675(int8_t sclk_pin, int8_t cs_pin, int8_t miso_pin) {
  _sclk = sclk_pin;
  _cs = cs_pin;
  _miso = miso_pin;
  //define pin modes
  pinMode(_cs, OUTPUT);
  pinMode(_sclk, OUTPUT);
  pinMode(_miso, INPUT);
  digitalWrite(_cs, HIGH);}
double MAX6675::readCelsius(void) {
  uint16_t v;
  digitalWrite(_cs, LOW);
  delay(1);
  v = spiread();
  v <<= 8;
  v |= spiread();
  digitalWrite(_cs, HIGH);
  if (v & 0x4) {
    // uh oh, no thermocouple attached!
    return NAN;
    //return -100;  }
  v >>= 3;
  return v*0.25;}
double MAX6675::readFahrenheit(void) {
  return readCelsius() * 9.0/5.0 + 32;}
byte MAX6675::spiread(void) {
  int i;
```

```
  byte d = 0;
  for (i=7; i>=0; i--)
  {  digitalWrite(_sclk, LOW);
    delay(1);
    if (digitalRead(_miso)) {
      //set the bit to 0 no matter what
      d |= (1 << i);}
    digitalWrite(_sclk, HIGH);
    delay(1);  }
  return d;}
  Phant::Phant(String host, String publicKey, String privateKey) {
  _host = host;
  _pub = publicKey;
  _prv = privateKey;
  _params = "";}
void Phant::add(String field, String data) {
  _params += "&" + field + "=" + data;}
void Phant::add(String field, char data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, int data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, byte data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, long data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, unsigned int data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, unsigned long data) {
  _params += "&" + field + "=" + String(data);}
void Phant::add(String field, double data) {  char tmp[30];
  sprintf(tmp, "%f", data);
  _params += "&" + field + "=" + String(tmp);}
void Phant::add(String field, float data) {
```

```
  char tmp[30];
  sprintf(tmp, "%f", data);
  _params += "&" + field + "=" + String(tmp);}
String Phant::queryString() {
  return String(_params);}
String Phant::url() {
  String result = "http://" + _host + "/input/" + _pub + ".txt";
  result += "?private_key=" + _prv + _params;
  _params = "";
  return result;}
String Phant::get()
  String result = "GET /output/" + _pub + ".csv HTTP/1.1\n";
  result += "Host: " + _host + "\n";
  result += "Connection: close\n";
  return result;}
String Phant::post() {
	String params = _params.substring(1);
	String result = "POST /input/" + _pub + ".txt HTTP/1.1\n";
	result += "Host: " + _host + "\n";
	result += "Phant-Private-Key: " + _prv + "\n";
	result += "Connection: close\n";
	result += "Content-Type: application/x-www-form-urlencoded\n";
	result += "Content-Length: " + String(params.length()) + "\n\n";
	result += params;
	_params = "";
	return result}
String Phant::clear() {
  String result = "DELETE /input/" + _pub + ".txt HTTP/1.1\n";
  result += "Host: " + _host + "\n";
  result += "Phant-Private-Key: " + _prv + "\n";
  result += "Connection: close\n";
  return result;
```

APPENDIX F3

Frimware cooding: mac6675.h

```
#ifndef max6675_h
#define max6675_h
#include "application.h"
class MAX6675 {
public:
    MAX6675(int8_t sck_pin, int8_t cs_pin, int8_t miso_pin);
  double readCelsius(void); double readFahrenheit(void);
  // For compatibility with older versions:
  double readFarenheit(void) { return readFahrenheit(); }
 private:
  int8_t _sclk, _miso, _cs; uint8_t spiread(void);};
class Phant {
 public:
    Phant(String host, String publicKey, String privateKey);
    void add(String field, String data);void add(String field, char data);
    void add(String field, int data);void add(String field, byte data);
    void add(String field, long data);
    void add(String field, unsigned int data);
    void add(String field, unsigned long data);
    void add(String field, float data);
    void add(String field, double data);
    String queryString(); String url();String get();
    String post(); String clear();
  private:
    String _pub  String _prv;
    String _host;String _params;
};
#endif
```

APPENDIX G1

Data collected: Experiment 1 Result

Table 2.1: Experiment 1 Result

tc1(°C)	tc2(°C)	tc3(°C)	tc4(°C)	timestamp	Time between post
57.25	51.75	57.25	51.75	40:24.2	00:03.7
58.25	52	57.75	52	40:20.5	00:03.4
58.25	52.5	58.25	52.25	40:17.0	00:06.7
59.25	53.5	59.25	53.75	40:10.4	00:03.3
60.25	54.25	60	53.75	40:07.0	00:03.3
60.5	54.25	60.25	54.5	40:03.7	00:03.5
61.5	54.75	61.5	54.75	40:00.2	00:03.2
61.75	55	61.75	55	39:57.0	00:06.6
62.5	56	63	56	39:50.4	00:03.5
63.75	56.25	63.25	56.5	39:46.9	00:03.3
64.5	57	64.75	57.25	39:43.6	00:19.5
69.75	60.25	69.75	60.25	39:24.1	00:03.3
70.75	61.5	70.75	61.5	39:20.7	00:04.1
71.75	63	72.25	62.5	39:16.7	00:03.3
74	64.25	73.75	64	39:13.3	00:06.8
76.25	66.5	76.5	66	39:06.5	00:03.3
78.75	67.5	78.5	67	39:03.2	00:02.7
93.75	77	93.25	76.75	39:00.5	00:00.0
99.25	81	99	81	39:00.5	00:00.0
84	70.5	83.5	70.5	39:00.5	00:00.8
80	68.75	79.75	68.5	38:59.7	00:28.0
103.5	84.25	102.75	83.25	38:31.8	00:03.6
107	85.75	107.25	86.25	38:28.2	00:03.3
111.75	90.5	111.75	89.75	38:24.9	00:03.3
116.5	94.25	116	93.5	38:21.6	00:03.3
120.75	96.75	120	96.5	38:18.3	00:03.3
125.25	101.25	124.25	100	38:15.0	00:20.8
165	141	163.25	139.75	37:54.2	00:03.3
172	148.75	170.5	147.25	37:50.8	00:03.5
178.25	157	177.5	155.25	37:47.3	00:03.3
182.75	164.75	181.75	164	37:44.0	00:03.3
186.75	169	187	168.75	37:40.7	00:03.3
190	174	189.75	172.5	37:37.4	00:03.3
189.5	181.25	189.5	180.25	37:34.1	00:03.2
191.25	179.25	191.25	179.5	37:30.9	00:07.0
192	179.75	192	180.25	37:23.9	00:03.3
192.25	180	192.25	179.75	37:20.6	00:03.3
192.25	180	192.75	180.5	37:17.3	00:03.4

191.5	180.5	191.75	180.5	37:13.9	00:03.6
189.5	182	190	181	37:10.2	00:03.6
187.25	183.25	187.5	183	37:06.6	00:03.2
185.75	182	186	183.25	37:03.4	00:03.6
184.75	179.75	185.25	180.5	36:59.8	00:03.3
182.75	177	184	177.25	36:56.5	00:01.1
175.5	172.25	176	171.5	36:55.4	00:05.2
180.25	175.25	179.5	174.75	36:50.2	00:11.9
178.5	173.5	178.75	173.5	36:38.3	00:09.7
174.25	170.5	174.75	171	36:28.6	00:03.6
170.75	168.25	171.5	169.25	36:25.0	00:17.1
162.25	156.25	162.75	156.75	36:07.9	00:03.3
158.75	152.75	159.75	152.5	36:04.7	00:02.8
157.75	154.5	158	154	36:01.8	00:03.6
156	156.75	157	155.75	35:58.2	00:03.3
155	155.25	155.75	155.25	35:54.9	00:03.7
153.75	155	153.75	154.5	35:51.3	00:06.6
149.25	146.5	149.25	146.5	35:44.7	00:03.3
146.5	145.25	146.75	145.75	35:41.4	00:03.3
143.75	142.75	144	143.5	35:38.1	00:03.6
140.25	135.75	141	136.25	35:34.4	00:03.8
136.75	131	137.5	132.25	35:30.7	00:14.2
112.25	96	113.25	97.5	35:16.5	00:03.7
105	88.25	106	88.5	35:12.7	00:03.8
98.5	75.25	99.5	77.25	35:09.0	00:03.3
91	64.75	92.25	66	35:05.7	00:03.5
83.75	58.75	83.5	59.5	35:02.2	00:04.1
75	52.75	75.5	53.5	34:58.1	00:03.6
66	46.75	67.5	47.25	34:54.5	00:03.6
57	43.75	58.5	44.75	34:50.9	00:03.5
49.5	39.75	51	41.5	34:47.4	00:03.3
41	34.25	43	35	34:44.1	00:03.4
36	31	36.75	32	34:40.7	00:03.2
31	27.5	31.75	27.75	34:37.5	00:09.3
29	26.5	29	26.75	34:28.2	00:03.3
29.25	27	29.25	27	34:24.9	00:03.2
29.75	27.25	29.75	27.25	34:21.7	

APPENDIX G2

Data collected: Experiment 2 Result

Table 2.1: Experiment 2 Result

tc1	tc2	tc3	tc4	Timestamp	Time responds	Time interval
27.5	27.5	29.25	28	21:27.7		00:00.0
35.75	32.25	36.5	32.75	21:32.1	00:04.3	00:04.3
45	38.75	47	39.25	21:36.3	00:04.2	00:08.5
56	44.5	57.5	45.75	21:40.4	00:04.1	00:12.7
65.5	50.75	67.5	52	21:44.4	00:04.0	00:16.7
75	56	75.25	56.75	21:48.8	00:04.4	00:21.1
84.25	64.25	85.5	65.5	21:53.0	00:04.2	00:25.3
93	73.25	93.75	73	21:57.5	00:04.4	00:29.7
100.25	78.25	102	80	22:01.6	00:04.2	00:33.9
109.25	85.75	110.25	87	22:06.0	00:04.4	00:38.3
118	98.5	119.5	99.5	22:10.3	00:04.3	00:42.6
126.5	102.5	127.75	101	22:14.7	00:04.3	00:46.9
135	103.75	135.75	103.5	22:19.0	00:04.4	00:51.3
158	127.75	159	127	22:38.6	00:19.6	01:10.8
163	128.25	163.25	128	22:42.7	00:04.1	01:14.9
167.5	127.75	166.5	127.25	22:46.7	00:04.0	01:19.0
168	127.5	168.75	127.75	22:53.2	00:06.5	01:25.5
171	128.25	170.75	127.75	22:57.2	00:04.0	01:29.5
174.75	127.25	175	127.75	23:01.4	00:04.2	01:33.7
176.5	131.25	177	132.25	23:05.5	00:04.1	01:37.8
178.75	133.5	179	133.75	23:09.6	00:04.1	01:41.9
180.25	138.5	180	139.5	23:13.7	00:04.1	01:46.0
180.75	140.75	180	141.25	23:17.7	00:04.0	01:50.0
180	140.25	179.5	140	23:21.8	00:04.1	01:54.1
181.75	141.25	182.25	142	23:25.9	00:04.1	01:58.2
183.5	145.25	184.25	146.5	23:30.2	00:04.3	02:02.5
186.25	150.25	186.25	150.25	23:34.3	00:04.1	02:06.6
187.25	150.5	187.5	149.75	23:38.4	00:04.0	02:10.7
190.5	148.25	191	149.25	23:42.7	00:04.3	02:14.9
191	153.25	191	152.75	23:47.1	00:04.5	02:19.4
190.75	147	189	146.75	23:51.7	00:04.6	02:24.0
189.25	143.75	189	143.25	23:56.0	00:04.3	02:28.3
194	145.25	193.25	145.25	24:03.5	00:07.5	02:35.8
198.25	147	197.25	148	24:07.5	00:04.0	02:39.8
199.75	145.25	201	145.25	24:12.1	00:04.6	02:44.4
189.5	142	190.75	142	24:20.2	00:08.1	02:52.5
202.75	143	202.5	143.25	24:20.2	00:00.0	02:52.5

200.75	144.75	200.75	145	24:23.3	00:03.0	02:55.5
198.5	142.5	198	142.75	24:27.3	00:04.0	02:59.5
201.75	139	199.75	139.75	24:35.4	00:08.2	03:07.7
198.5	139.5	198.75	138.75	24:39.7	00:04.3	03:12.0
199.25	141.5	198	141.5	24:43.8	00:04.1	03:16.0
194	136.75	195.25	137.5	24:51.9	00:08.2	03:24.2
193.25	137.25	194	136.5	24:56.4	00:04.4	03:28.6
194.75	136.75	194.5	136	25:00.8	00:04.4	03:33.1
195.25	141.75	195.75	141	25:05.0	00:04.2	03:37.3
194.5	144.25	194.75	145.5	25:09.4	00:04.4	03:41.6
191	149	190.75	149.5	25:13.4	00:04.0	03:45.7
183.5	140	182	139	25:17.5	00:04.1	03:49.7
173	130.25	172	129.5	25:21.5	00:04.0	03:53.8
164	123.5	162	122.5	25:25.6	00:04.1	03:57.8
154.75	118	153	116.5	25:29.8	00:04.2	04:02.1
146.25	111.25	145.25	110.5	25:34.2	00:04.4	04:06.5
138.5	105.75	137	104.75	25:38.3	00:04.1	04:10.6
131.25	98.75	129.5	98.5	25:42.5	00:04.2	04:14.7
124.75	94.75	124	94	25:46.5	00:04.1	04:18.8
117.75	90.25	117.25	89.75	25:51.0	00:04.5	04:23.3
111.75	85	111.5	84.25	25:55.2	00:04.2	04:27.5
106.75	80.5	106.25	80.5	25:59.3	00:04.1	04:31.5
103.5	76.5	103	76.25	26:03.4	00:04.1	04:35.7
99.5	73.75	100	72.75	26:07.8	00:04.4	04:40.0
97	71.25	97.25	71.25	26:12.0	00:04.2	04:44.2
94	68.75	94	68.5	26:16.0	00:04.0	04:48.3
91	66.25	90.5	66.5	26:20.2	00:04.1	04:52.4
88	64.5	87.5	64.5	26:24.6	00:04.4	04:56.8
84.5	63.5	84.75	63.25	26:28.6	00:04.1	05: 00.9
82.5	63	82.25	63.25	26:33.0	00:04.3	05:05.2
80	62.5	79.25	62.75	26:37.3	00:04.4	05:09.6
78	62.75	78.5	62.75	26:41.4	00:04.1	05:13.7
76.75	62.75	76.5	63	26:45.6	00:04.2	05:17.9
75.5	63.5	75.5	63.5	26:49.7	00:04.1	05:21.9
73.75	62.5	73.75	62	26:53.8	00:04.1	05:26.0
72.5	61.5	72	61.75	26:58.1	00:04.3	05:30.3
71.25	60.25	71.25	60.25	27:02.2	00:04.1	05:34.4
70.25	59.5	70.5	59	27:06.3	00:04.1	05:38.5
70	58.5	69.5	58.75	27:10.7	00:04.4	05:43.0
69.25	58.75	69.5	58.75	27:12.9	00:02.2	05:45.2
67.75	58.5	68.25	58.25	27:17.3	00:04.3	05:49.5
66.75	56.25	66.25	56.75	27:23.6	00:06.3	05:55.9
66.5	55	66.25	55	27:27.9	00:04.3	06:00.2
65.75	54.5	65.75	54.25	27:32.0	00:04.1	06:04.2
65	53.25	64.75	52.5	27:36.3	00:04.4	06:08.6

64.25	52.5	64	52.5	27:40.4	00:04.1	06:12.7
63.25	52	63.25	52	27:44.8	00:04.3	06:17.0
62	51.25	62.25	51	27:48.9	00:04.1	06:21.1
62	50.5	62.5	50.75	27:53.0	00:04.1	06:25.2
61.75	50.5	60.5	50.75	27:57.0	00:04.0	06:29.3
60.5	50.5	61	50.75	28:01.1	00:04.1	06:33.3
60.25	50.75	60	50.25	28:06.7	00:05.7	06:39.0
59.5	50	59.25	50	28:11.1	00:04.4	06:43.4
58.25	49.75	58	49.75	28:17.7	00:06.5	06:49.9
57.5	49.5	57.5	50	28:21.9	00:04.3	06:54.2
57	50	57	50	28:26.0	00:04.1	06:58.3
57	50.25	56.5	50	28:30.3	00:04.3	07:02.6
56.5	49	55.75	49	28:34.4	00:04.0	07:06.6

APPENDIX H1
Multiplexer schematic and PCB Layout

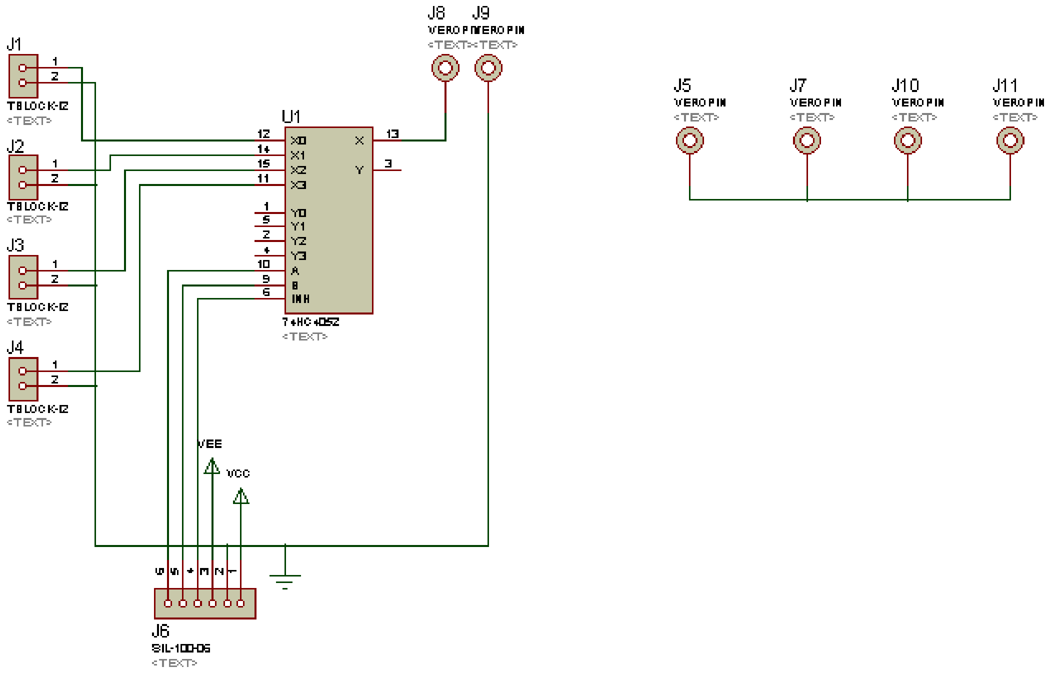


Figure 6.1: Multiplexer schematic

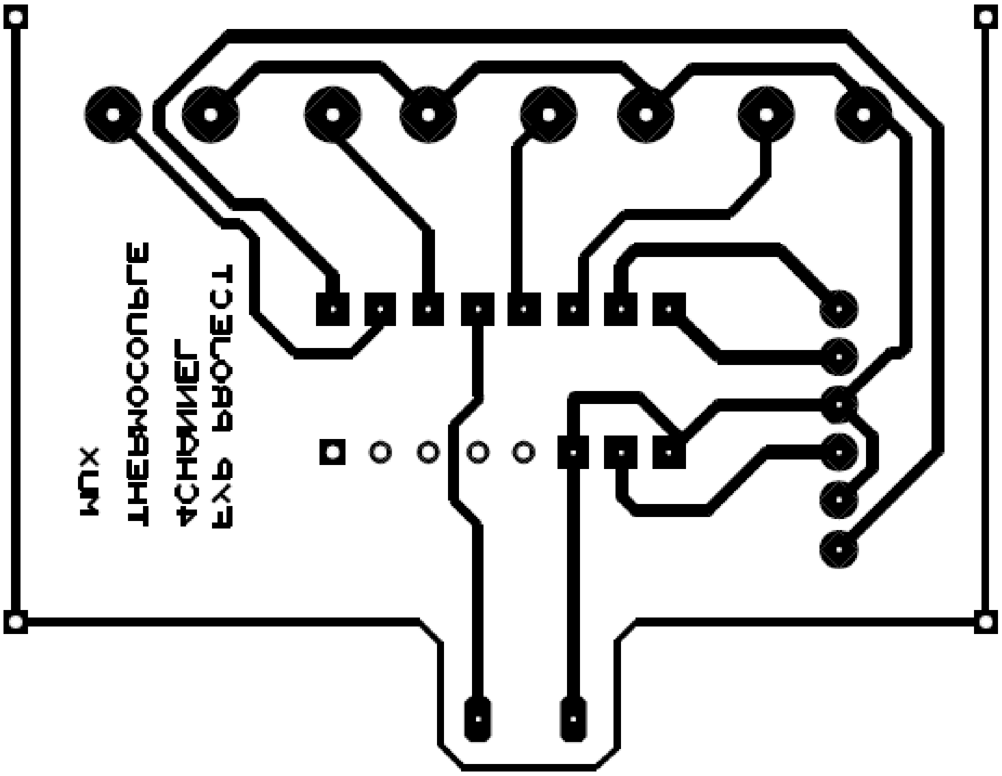
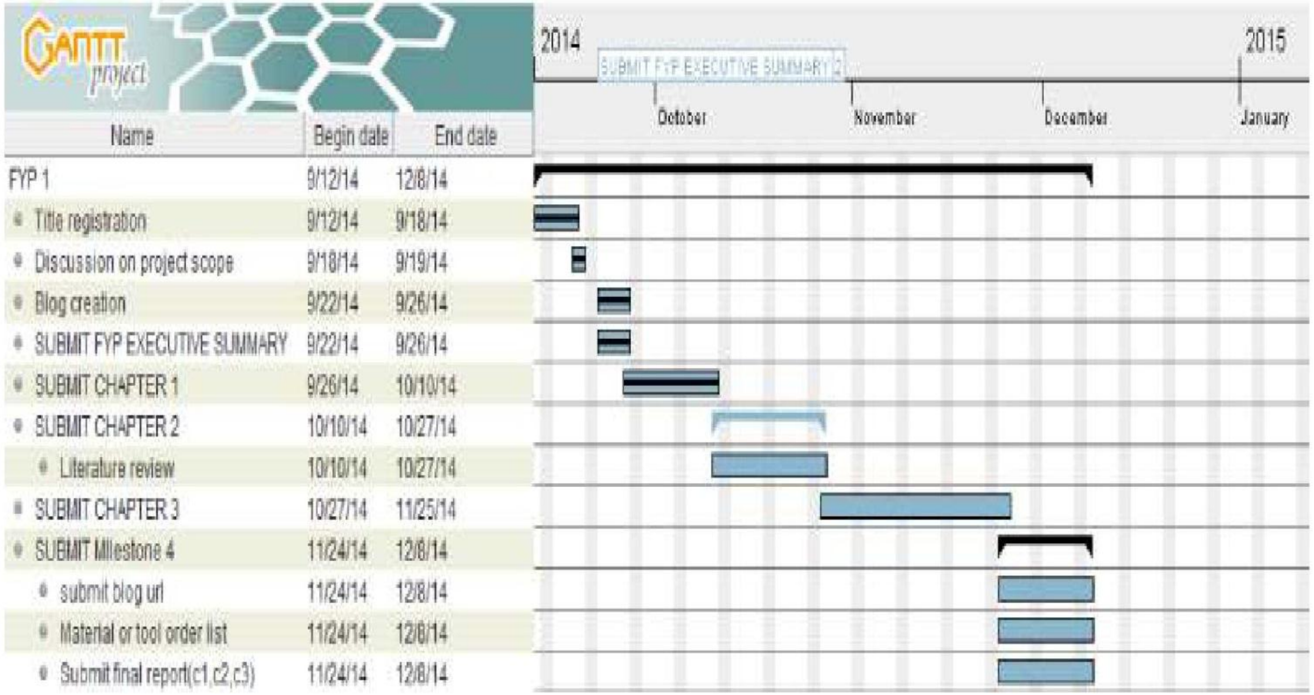


Figure 6.2: PCB Layout

APPENDIX I1

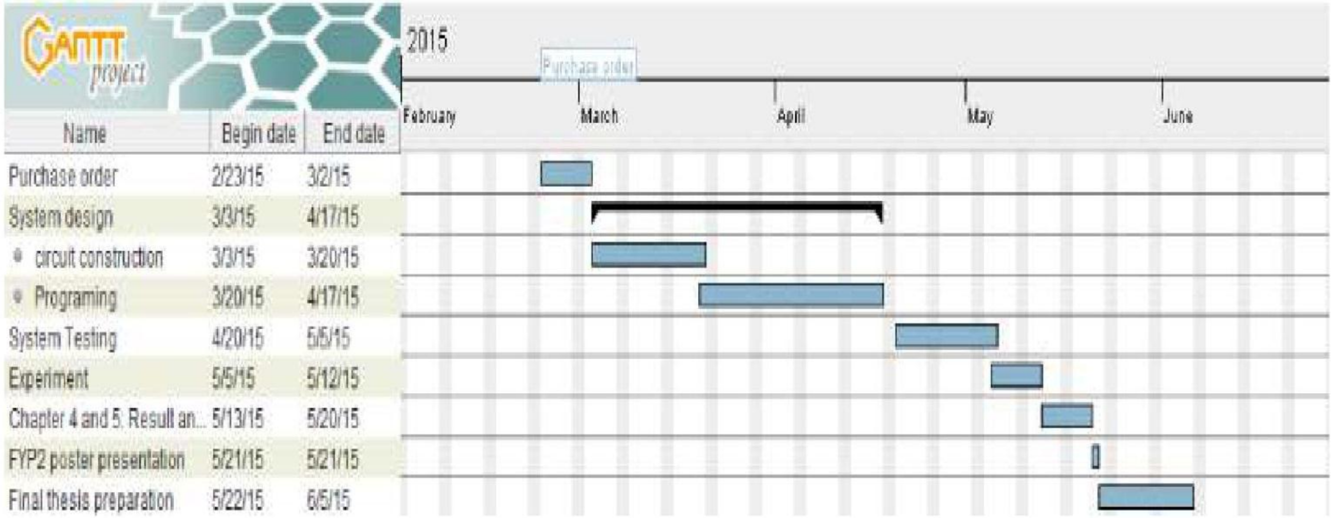
Project Gantt chart: FYP 1



Name	Begin date	End date
FYP 1	9/12/14	12/8/14
Title registration	9/12/14	9/18/14
Discussion on project scope	9/18/14	9/19/14
Blog creation	9/22/14	9/26/14
SUBMIT FYP EXECUTIVE SUMMARY	9/22/14	9/26/14
SUBMIT CHAPTER 1	9/26/14	10/10/14
SUBMIT CHAPTER 2	10/10/14	10/27/14
Literature review	10/10/14	10/27/14
SUBMIT CHAPTER 3	10/27/14	11/25/14
SUBMIT Milestone 4	11/24/14	12/8/14
submit blog url	11/24/14	12/8/14
Material or tool order list	11/24/14	12/8/14
Submit final report(c1,c2,c3)	11/24/14	12/8/14

APPENDIX I1

Project Gantt chart: FYP 2



Name	Begin date	End date
Purchase order	2/23/15	3/2/15
System design	3/3/15	4/17/15
● circuit construction	3/3/15	3/20/15
● Programing	3/20/15	4/17/15
System Testing	4/20/15	5/5/15
Experiment	5/5/15	5/12/15
Chapter 4 and 5. Result an...	5/13/15	5/20/15
FYP2 poster presentation	5/21/15	5/21/15
Final thesis preparation	5/22/15	6/5/15

APPENDIX J

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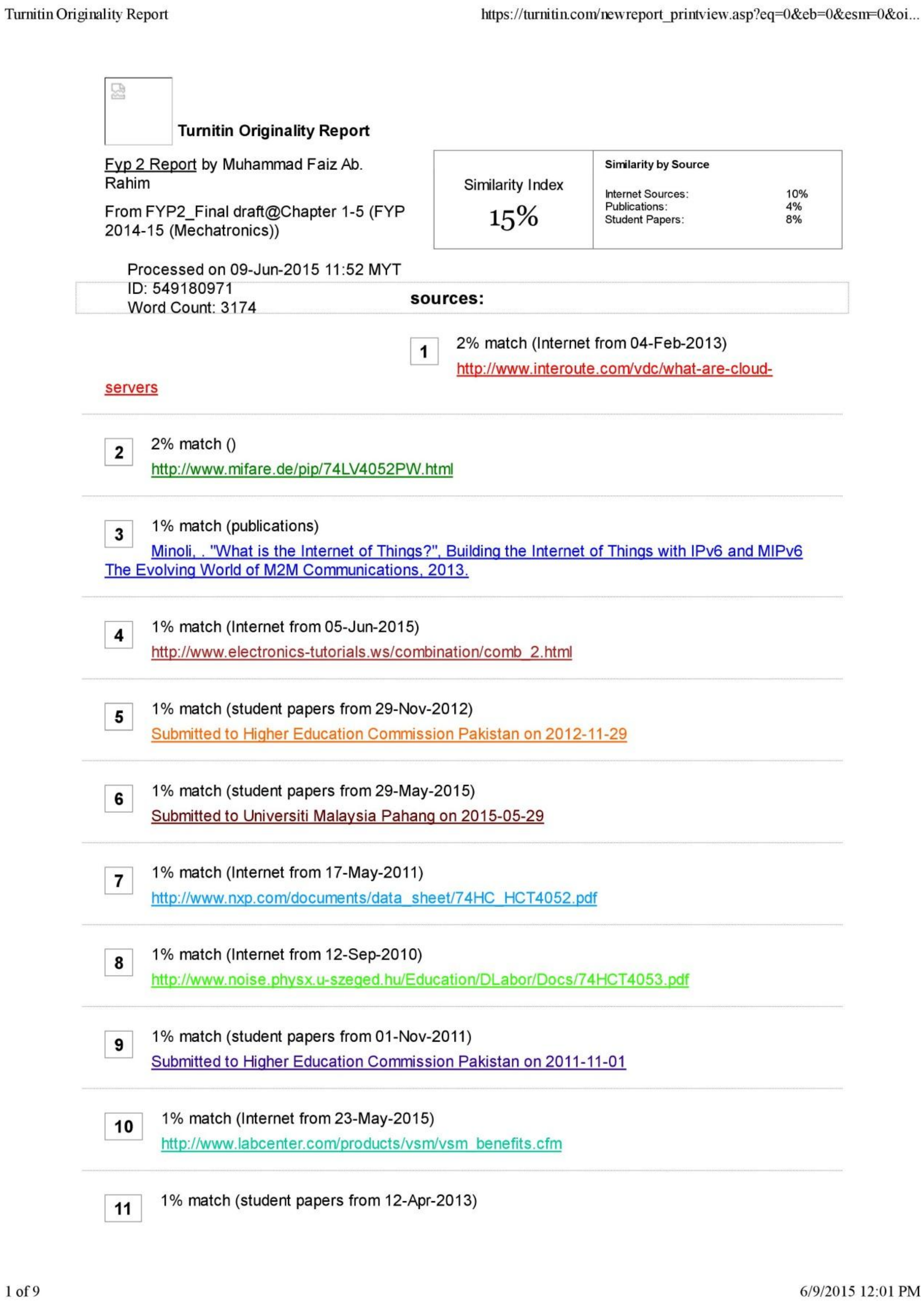

Turnitin Originality Report

Fyp 2 Report by Muhammad Faiz Ab. Rahim

From FYP2_Final draft@Chapter 1-5 (FYP 2014-15 (Mechatronics))

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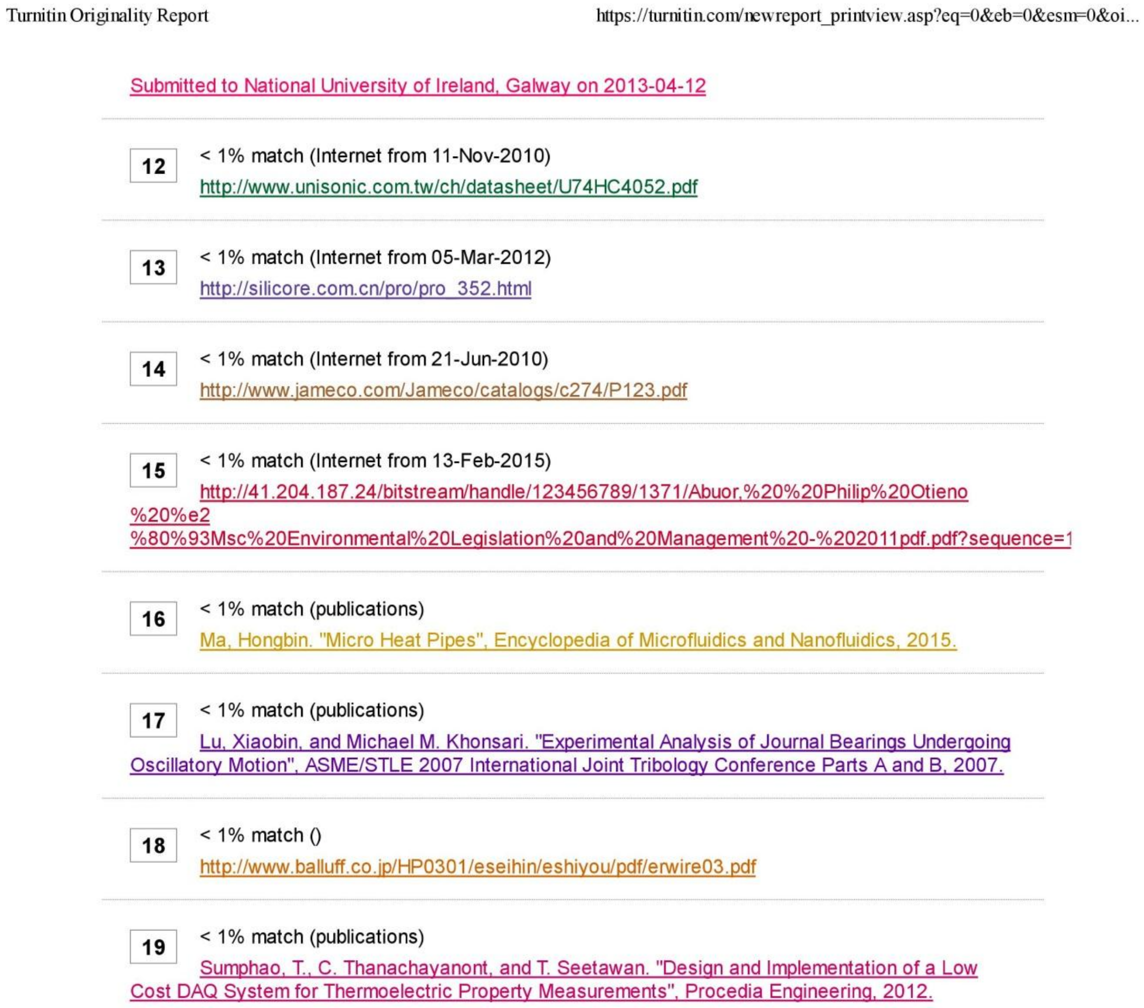

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