Electrical Subsystem for the
Renewable Energy Burning Cookstove and Surface Environment (REBCE)

A Major Qualifying Project Report:
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

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Approved:  
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Executive Summary

This major qualifying project designed and implemented a stove that can run off wood burning and other burning materials as well as electricity. In addition to the design of the stove, an electrical control system was implemented to increase efficiency as well as to monitor the stove. Gas sensors and temperature sensors around the stove allow for proper monitoring and allow for the stove to be automatically controlled via DC motors that control the airflow through the stove. Overall, the efficiency and the functionality of the stove are a great improvement over what currently exists on the market.

For the purposes of submission, the project report was divided into two parts one for the overall project and another for the electrical subsystem.

The design of the electrical subsystem is adequately flexible to accommodate the design requirements of the overall cookstove implementation.
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Acknowledgements

There are several people that without which this project would not have gotten as far as it did. The first person to be thanked is Professor Mustapha Fofana without whom this project would not have existed. Another that helped immensely with the structure and guidance of this project is Professor Robert C. Labonté. I would also like to thank Jeff Hook who helped with organizational techniques and the location of various electrical devices that would allow easier interfacing of the overall system. Finally, my thanks go to Ramsey Abouzahra who provided information about processor programming and functionality.

I would also like to thank the staff of both the ECE and ME departments who made this project possible.
1.0: Introduction

Throughout the world, approximately two million annual deaths are attributed to smoke inhalation due to poorly ventilated or unventilated combustion used for cooking. These deaths are most heavily concentrated in third world nations as well as impoverished regions, and unfortunately, they are all completely preventable. Cooking conditions for these areas usually involve dwellings completely filled with smoke from an open fire, with the family still inside. The current cookstove technology ranges from three stones around a fire, to homemade wood stoves, which are usually unsafe in terms of ventilation and thermal insulation. The inefficiency of these systems along with improper fuel selection results in incomplete combustion, generating millions of tons of carbon emissions each year. Carbon emissions produced by people cooking with solid fuels is still a large contributor to the increasing amounts of greenhouse gasses in our atmosphere. Overall, a large portion of the world still does not have the safe, clean, and energy efficient standards of cooking as more developed nations are accustomed. This brings about a negative impact on general health, as well as the environment.

The goal of this project is to develop an affordable cookstove that is safe, reliable, energy efficient, and adaptable to various renewable and conventional
fuel sources. The end user of this product can only afford to pay a few hundred dollars on a commercial wood burning cookstove, therefore the product needs to be designed for a cost of under $500. The product needs to be resilient and maintainable, utilizing intuitive design and standard components, because the end user cannot afford to buy a new stove should the cookstove fail. The product needs to be safe in terms of monitoring levels of harmful emissions in the dwelling and alerting the user of hazardous conditions. The cookstove should also be properly thermally insulated, with the exception of the heating element, so the user or a child will not be severely burned upon making contact with the outer surfaces of the stove. The cookstove needs to be well ventilated to prevent harmful emissions from entering the dwelling. The product needs to induce more complete combustion to reduce harmful emissions and increase efficiency. Because electricity is an energy source limited to developed nations, and consumer batteries are an expensive and inefficient method of power, the cookstove needs to be capable of powering its system without a readily available electrical source. Oils and natural gas are expensive fuel sources with limited availability to the targeted end user. Therefore, the cookstove needs to be capable of combusting the various fuel sources available to a region, including bio-mass, wood, wood pellets, and fire logs. Overall, this product should save the end user money by reducing fuel usage and increasing energy efficiency. Affordability
will be achieved by proper selection and effective use of materials and components, as well as reducing operating costs for the user. Safety will be achieved by reducing fire and injury hazards, monitoring harmful gas levels, and implementing an effective ventilation design. Fire and injury hazards will be reduced by proper insulation of the cookstove. Hazardous emissions will be monitored through an embedded computer system. Effective ventilation will be achieved by proper design of the cookstove flue. Energy efficiency will be achieved by increasing complete combustion in the firebox, which in turn, will also reduce harmful emissions. Reliability will be achieved with a sturdy structural design with resilient materials, and the selection of reliable and efficient electrical components.

In the next chapter, I will discuss current cookstove designs, emissions data of various fuel sources, and the electrical components of the embedded safety and control system. In chapter three, I will discuss the design and implementation, as well as the analysis and results of various components of the cookstove. Finally, chapter four will discuss our conclusions about various functions and constraints, along with our recommendations for improvement.
2.0: Background & Requirements

The electrical portion of this project will ultimately function as a monitoring, warning, and control system. This portion of the project is necessary to improve the fuel efficiency as well as the safety of the cookstove. The system will achieve its goal of regulating burning temperatures by monitoring temperatures of the inside and outside of the stove. By keeping track of the temperatures in and around the stove, the electrical subsystem will regulate these by using a geared dc motor to control the overall air intake. The system will also be able to control heating coils for stovetop and oven cooking. The electrical subsystem will also employ LEDs and a buzzer to inform the user about unsafe levels of harmful gasses around the stove. The system will also have an LED to indicate there is combustion happening in the stove. The user will be able to adjust the temperature of the stove with up and down arrow buttons. Finally the electrical system will have an LCD screen to provide the user with some basic information such as temperature of the cooktop, cooking timer and burning and igniter fuel indicators. Overall all of these features will be necessary in order to make the stove as easy to operate as pushing a button or turning a knob and will ultimately make the stove much safer and fuel-efficient.
The stove is to be capable of working with burning materials as well as electricity. If the consumer has access to electricity they can use the stove with the electrical coils for cooking instead of burning materials or even use both at the same time for faster cooking. This will not only decrease the output of more harmful gasses but also decrease the time it takes to cook a meal. Since electrical coils heat quickly, waiting time will be reduced and cooking time decreased. In addition to having electrical coils as well as a combustion chamber increases the marketability of the stove to anyone who wants the versatility. Overall, having a stove that can function on both electricity and burning materials is a substantial part of the justification for the market of the stove.

The electrical system will have to be capable of running off a small amount of electricity generated either by a small solar panel or the heat of the stove. The heat of the stove can be converted into electricity in many different ways, however two ways have proven to be the most feasible for this project. The first of the ways of converting the heat of the stove into electricity is to use a Stirling engine that would push a magnetic piston through coils of wire in a linear motion. This idea comes from the simple hand-powered flashlights that are shaken to generate electricity to power the flashlight. The second way of converting the heat to electricity is to use an electrical device called a TEG (Thermoelectric Generator) module, which is done by a process called the
“Seebeck Effect” that converts temperature differences between two thermal plates directly into electricity. Solar panels are also a considerable power option however solar energy is inconsistent and would therefore require some battery storage that increases the overall price of the project. Finally we considered wind power however this is both inconsistent and considerably more expensive than the other options considered due to the high precision and tolerances in the manufacturing of the moving parts. Overall The TEG modules or solar panels would be preferable since they are solid-state devices thus decreasing the noise and maintenance costs. Using a Stirling engine requires moving parts, which can mean breakdown of the stove and this is not acceptable since the end user may not have the funds or the means to repair it.

The system will use feedback loops in order to regulate temperatures inside the stove better and better over time creating the optimal hysteresis loop just as a thermostat does. This temperature control will be achieved by monitoring the differences between the desired and actual temperatures as well as movement of the motor controlling the air intake. As the system runs for more uses and even as humidity changes it will be able to adapt by constant monitoring and adjusting.

In order to achieve all of the functionality described, the system will use a microprocessor. The choice of the microprocessor will be determined in part by
the availability of power generated by the Thermoelectric Generator (TEG) modules. It will also have to be fast enough to achieve all the monitoring, controlling and reporting in a timely fashion. Finally the microprocessor must be an affordable model as the overall stove design cannot cost any more than $500 USD to the consumer. For design purposes an Atmel microprocessor from the ATmega32 series was selected for building and testing. This Atmel device can be replaced with a more inexpensive, and energy efficient microprocessor in the manufacturing stage.

Several TEG modules have been examined for powering the electrical subsystem. The first of the modules is the TEP1-1264-1.5. This module generates 8.6VOC (Volts Open Circuit) with a hot side temperature of 230°C and cold side temperature of 50°C. With this output voltage and output energy of about 5.4W this device should provide adequate power for the electrical subsystem. Two additional were examined: the TEP1-1265-0.8 and the 0.6. These two modules produce open circuit voltages of 8.7V and output wattages of 10.5 and 14.7 respectively. Overall the TEP1-1264-1.5 is the most cost effective for the application and is recommended for the final design.

During the research into designing the electrical control and safety system one project/product that is similar and could be considered competition for our cookstove design was discovered. The stove found in researching was designed
by a team of engineers in Nepal and is called the Batho Chulho [1], which means smart cookstove in Napalese. The Batho Chulho can be seen below in a breakdown view (Figure 1). This stove uses a microprocessor system to control a flue vent that regulates airflow and control the burning temperature. The Batho Chulho also has an LCD display with indicators to the cooking mode. This consists of multiple temperature ranges of the stove and a knob to increase or decrease the temperature. The LCD panel also displays a cooking timer controlled by a cooking time knob. It also indicates igniter and burning-fuel levels, as well as battery-power level. Finally the system includes a power LED to inform the user that combustion is occurring inside the stove. The Batho Chulho stove is estimated to cost around $37.50 and has an operating cost of around $0.15 per briquette. These briquettes are estimated to last for two cooking sessions for a family of 5 people. There is also operating costs of $1.50 and $1.00 every 2 months for a battery, and lighter respectively [1].
Figure 1: Breakdown View of the Batho Chulho [1]

Although the Batho Chulho is much less expensive, it does not include all of the added functionality and safety measures that our project cookstove will require. Specifically, the Batho Chulho lacks a harmful gas monitoring and reporting system. Safety is a very important element for this project since one of the biggest concerns is to keep the user safe while they are using the stove. The Batho Chulho also lacks the ability to exhaust smoke from the stove any faster than the air flowing through it. In comparison the stove that is being designed for this project will have a large size ducting sufficient for the ventilation of any gasses being formed. Finally the Batho Chulho is a much smaller stove than the REBCE and is only a single burner with no oven making cooking for a large
group difficult. Overall the REBCE should have an advantage over the Batho Chulho since it has some added safety features, more ways of increasing the burning efficiency, and can cook for a large family.
3.0: Design and Implementation

3.1: Design Overview

The design of this system has been mapped-out into an easy to understand block diagram (Figure 2). It can be seen in the diagram that the center of the system is the microprocessor. To the left of the microprocessor is the power system including wall power and the TEG modules along with the battery-charging circuit. To the top of the microprocessor are all of the various sensor inputs including gas sensors, thermal resistive sensors, and potentiometers. Finally, all of the outputs of the system are shown below the microprocessor and include: the LCD screen, LEDs, DC motors, and a buzzer. All of these elements of the electrical subsystem are described in more detail in the implementation section that follows.
Figure 2: Circuit Design Block Diagram
3.2: Implementation

3.2.1: Processor

The processor that is being used to implement this design is the ATmega32-16PU. This is an 8-bit AVR processor manufactured by Atmel. The processor is set onto an Olimex development board that has voltage regulation onboard and can be powered by either 9-12V DC or 6-12V AC. The development board also has an LED, a single button, RS232 port, and JTAG connector. The JTAG connector is connected through USB via a programmer that converts USB to JTAG. The software code involves interfacing with various I/O devices as well as feedback loops between the temperature sensors and the vent-controller motors. In the aggregate these form the hysteresis loop which will regulate the temperature of the stove. For programming software IAR kickstart for AVR processors as well as another freeware program called AVRstudio 5.0 are being used. IAR kickstart can program the board directly while AVRstudio 5.0 requires a secondary program called WinAVR to download the compiled code. While both programs work fine for programming of our ATmega32 AVR processor, IAR kickstart does not include the library of header files for use by the processor. As a consequence it was more difficult to get files downloaded to the microprocessor. Both systems are capable of programming the AVR processor
through the USB programmer. The development board and USB programmer can be seen in the diagram below (Figure 3).

![Figure 3: Olimex 40 Pin Development Board (left) and USB Pocket Programmer (right)](image)

For design purposes and due to time constraints, an MSP430 was used to design and test the functionality of the electrical control system. The code for this processor is provided in the appendix of this report. These processors are designed for very low power consumption and are readily available for use in the ECE laboratories. The functionality requirement of the code is to read potentiometer and thermistor values and control a DC motor that opens and closes the air intake valve of the stove.
3.2.2: Power System

The power system is comprised of several components. These include: an AC/DC converter for DC power obtained from a wall outlet, AC and DC voltage regulators, Thermoelectric Generator modules, and Battery Storage. There is also power distribution portion in order to be able to charge the batteries at the same time as running the control system.

3.2.2.1: Wall Power

In order to utilize 120V, 60Hz wall power an AC/DC converter circuit is required to regulate the wall power down to 5VDC. This AC/DC converter circuit has not be implemented in this MQP due primarily to time and design requirement constraints. However, if needed an AC/DC converter by ROHM part number BP503405 would be used to convert the wall power down to 5VDC. 5VDC is adequate for powering the processor and all of the I/O devices of the prototype. In the final design implementation, however, will require a circuit to be designed that is capable of supplying slightly over $1A_{\text{max}}$ for the entire system. At that level there should be enough energy to run all I/O devices simultaneously.
3.2.2.2: Thermo-Electric Generation

In researching renewable energy sources devices called TEG modules were found. These modules utilize a process called the “Seebeck Effect”, a process which turns a temperature differential across two ceramic plates into electricity through NPN junctions. The modules were tested on top of an electric range sandwiched between two heatsinks. The two modules were wired in series and tested, producing a maximum of about 4.2VDC. Consequently, it is expected that an array of six of these modules can be expected to achieve adequate power for the entire system. The six of these modules will be placed on one of the burn chamber walls and will have heatsinks on the opposite side to keep the temperature differential as high as possible. Because the voltage output of these modules can vary and is not always producing current we need both battery storage as well as voltage regulation to charge the battery storage cells at a constant voltage. In some cases a battery charging circuit will also be required but can easily be purchased as an IC along with some battery cells.

3.2.2.3: Voltage Regulation

As mentioned above, the output voltage of the TEG modules is not always consistent as it is a function of the temperature differential between two ceramic plates. In order to regulate this voltage to a constant supply a DC voltage regulator is required to charge a battery or provide voltage to a charging circuit.
While not a requirement for this prototype design, a small voltage regulator IC, as well as some additional circuitry will be designed to properly divide the power so that the battery can be charged while the system is being run.

3.2.2.4: Battery Storage

When adequate energy is not available from wall power, battery backup that is charged by both the TEG modules and wall power will be utilized to power the system. This will allow the circuit to be functional even when wall or heat power is not available for a period of time, until the stove heats up again or wall power is reestablished. In order to allow the batteries to charge, power must be distributed correctly so the system can be run at the same time as charging.
3.2.3: Sensor Inputs

As described below, the system will include multiple sensor inputs. The sensors that will be used in this system include various gas sensors, thermal resistive sensors, and potentiometers.

3.2.3.1: Gas Sensors

This project will include various gas sensors including: carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄), nitric oxide (NO), and nitrogen oxide (NO₂). All of these gas sensors will be connected to and monitored by the Analog to Digital Converter (ADC) of the microprocessor. Interrupts to the microprocessor will trigger if any of the levels on any of the sensors reach a certain threshold. This threshold for each gas will be the corresponding ppm at which the gas becomes dangerous and toxic to the individual breathing it in. All of these sensors will be placed around the cookstove, as that is the area we want to ensure has good air quality. If all the sensors are found to be within safe levels then the area is safe for cooking, however upon reaching any unsafe levels the microprocessor will sound a loud beeping buzzer alerting the user to evacuate the area. The microprocessor will also shut off airflow to the stove causing the fire inside the burn box to extinguish. Overall the gas sensors will ensure the user is not breathing any harmful gasses while cooking.
3.2.3.2: Thermal-Resistive Sensors

This design component includes various temperature sensors that will also be read by the microprocessors ADC circuitry. These values, once calibrated, will allow the microprocessor to determine how much to open or close the air intake valve in order to reach the right temperatures on the stovetop and inside the oven. These sensors will be placed at various points around the stove and shielded to ensure they are not exposed directly to any open flames.

3.2.3.3: Potentiometers

The system will include various potentiometers: two to control the stovetop heating coils, and one for control of the oven temperature. These controls will work by being calibrated with the ADC of the microprocessor and the lowest and highest settings of each potentiometer will correspond to all-the-way off up to full heat.
3.2.4: Outputs

The system will include various outputs in order to communicate certain things to the user. These outputs will be explained further below and will include: LCD screen, Feedback LEDs, DC motors, and a buzzer.

3.2.4.1: LCD

The LCD screen in this project is used to display the oven temperature as well as a clock and cooking timers. The LCD screen being used for this project is a small black and white 8-bit device. The LCD screen chosen for the system has internal memory to store 8-bits of data. The screen is communicated to by 8 parallel bus lines by the processor in a sequence of 8-bit pages. The LCD screen then prints page-by-page to the 128x32 pixel screen starting in the top left and moving to the right and down as a book would be read. The LCD screen also includes a backlight feature so the clock can be seen at night.

3.2.4.2: LEDs

This system includes multiple LEDs for various functions. First there will be bright-white LEDs mounted above the cooking surface in order to allow for nighttime cooking. There will also be a red LED to indicate that the stove is hot and warns the user not to touch it. Finally there will additional LEDs that will be
illuminated to notify the user if the gas sensors determined values exceed their thresholds which indicate what gasses have been detected.

3.2.4.3: DC Motors

For oven heating and cooling, dc motors are included in the project to demonstrate the opening or closing of valves throughout the stove. The DC motors have gear ratios such that the arm will have adequate torque and low RPMs to ensure accurate positioning when opening or closing of the valves. In the final design, a motor with an RPM feedback line is used in order to determine how accurately opening or closing the valve is achieved. The motors are connected in an H-Bridge configuration so that switching of voltage across the DC motors reverses the polarity and allows the motors to spin in both directions.

3.2.4.4: Buzzer

As mentioned above in the gas sensor section, a buzzer will be implemented in order to notify the user of any unsafe conditions being experienced by the stove. In order to ensure that the buzzer is loud and piercing enough, the buzzer will have a sound pressure level of 80dBA @ 12V and 0.1m and a frequency of over 2kHz. The buzzer chosen has an internal crystal oscillator and therefore needs only to be provided with a DC voltage to be operated. In order to make the buzzer even more noticeable, it will beep rather
than just staying on constantly and will go off when the gas levels are back within a safe range.
4.0: Project Overview

For this project, all of the essential functionality described in the design and implementation sections above have been included in the hardware and software of the electrical subsystem. Once the mechanical design of the overall system has been completed a more fully functional electrical system will be implemented. A fully functional electrical system will be implemented in prototype form to achieve the full functionality required by the cookstove. For example, potentiometers will be monitored in order to decide the range of control required to achieve full functionality. In addition, the relationship between the values of the potentiometers and thermal resistive sensors will be determined. At the same time, development of the prototype electrical system should include the electrical power circuitry required by the system.

The diagram shown below (Figure 4) indicates which parts of the electrical system have been implemented for this MQP. The block diagram shown below is color coded. The green squares are the components that were implemented for this MQP, the orange squares are the ones that may be implemented if time permits, and the red squares are the components that will not be implemented for this MQP. The block diagram below is similar to the one provided in the design overview section of chapter 3 with the exception that it has color coded squares to indicate what the goals of this MQP are.
An overall parts list for all the components used for this MQP can be seen in the excel spreadsheet below (Figure 5). The cost of all the parts is approximately $150.00 and is under $100.00 at the bulk prices.

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<td>Air Quality Control Sensor</td>
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<td><strong>Outputs</strong></td>
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**Figure 5: Parts List for MQP parts**

Finally, the overall circuit diagram for the system can be seen below (Figure 6) and illustrates how each of the components is wired to the processor. The
processor can be seen in the center, TEG modules to the right and the AC power source just above the processor. The thermistors at the top represent the gas sensors. The LCD module, buzzer, and the warning and surface lighting LEDs are included to the right. Finally we have the motor, keypad, and power switch just to the left of the processor.
Figure 6: Circuit Diagram for Overall System
5.0: Conclusions

This project still has some untied ends in terms of the implementation; however, everything is explained and laid-out in a finalized design that somebody taking on this project as a continuation would be able to pick-up from where this project left off. In this project an overall design was achieved and a small amount of the functionality was implemented. Future work could include completely implementing the design so it is fully functional as well as optimizing for a better processor and actually interfacing the device with the stove. Overall this project was very informative and interesting to work on, especially since it was a multidisciplinary project and dealt with very real issues. In the end, all the partners on this project agreed that this design is the best fitting to the requirements for the REBCE. If this product was going to be marketed some implementation still remains, however once done the design should be appealing to a decent size market.
Works Cited


<http://www.archive.org/stream/BathoChulho/bathochulho_djvu.txt>
Appendix A

/* NEC: REDCE
Advisor: Robert Labonte
Jack Knight
*/

#include <msp430x44x.h>
#include <stdlib.h>
#include <string.h>     // for some string functions

().'/* GLOBAL VARIABLES */.******************************

char *LCD = LCDMEM;       // pointer to LCD Memory Segments. Pretty cool, got this idea from T1-website
unsigned int timer;
unsigned int timer_length;
char disable_interrupt;
char disabled;   //not in ISR, but helpful for debug

/****** LCD CONSTANTS *******/

#define a (0x80)    // definitions for LCD segment shifts on the Olinux LCD. 4-Mux operation is assumed
#define b (0x40)
#define c (0x20)    // TI's MSP430F449 User Guide (look for LCD Controller, then 4-Mux).
#define d (0x01)    // add 441STK-2 schematic. You will need ALL these 3 when defining
#define e (0x02)    // each number or character. Remember, the Olinux LCD doesn't use a LCD driver!
#define f (0x00)
#define g (0x04)    // You tell the LCD what characters to display. It's very time consuming!!
#define h (0x10)

/***** FUNCTION DECLARATIONS *******/

void shortDelay(unsigned int ms);  
void init_sys(void);
void disable_timer(void);
void enable_timer(void);
void runtimer(void);
void stoptimer(void);
void reteupADC(void);
unsigned int pollADC0(void);
unsigned int pollADC1(void);
void reteupMotor(void);
void motorOnCW(void);
void motorOnCCW(void);
void motorOff(void);
void clearLCD(void);
void initLCD(void);
void shortDelay(int dSpeed);
void writeLetter(int position, char letter);
void writeWord(const char *word, int repeat_times);
void writeNumber(int long number);
void writeSentence(const char *word, int scrollForever);

A-1
int main()
{
    init_sys();

    motorOnCNW();
    motorOff();
    motorOnCCW();
    motorOff();

    // float voltage = 0;
    // float Vthrm = 0;
    // unsigned int i = pollADCO();
    // unsigned int j = pollADC1();
    // voltage = (0.0007564)x-0.000572;
    // Vthrm = (0.000293x)+0.000214;
    //
    // while((voltage > 0.00 as voltage < 1.2) == 1)  // for low temperature setting
    // {
    //    unsigned int i = pollADCO();
    //    unsigned int j = pollADC1();
    //    voltage = (0.0007564)x-0.000572;
    //    Vthrm = (0.000293x)+0.000214;
    //    //
    //    Vthrm = 1.0;
    //    //
    //    if(Vthrm < 1.1 as Vthrm > 0.00)
    //    writeSentence("LOW TEMPERATURE READY",0);
    //    else if(Vthrm > 1.71)
    //    {
    //        motorOnCCW();
    //        // else turn motor in opposite direction opening the flue
    //    }
    //    else
    //    {
    //        motorOnCNW();
    //        // else turn motor in opposite direction opening the flue
    //    }
    // }
    // while((voltage > 1.00 as voltage < 2.2) == 1)  // for medium temperature setting
    // {
    //    unsigned int i = pollADCO();
    //    unsigned int j = pollADC1();
    //    voltage = (0.0007564)x-0.000572;
    //    Vthrm = (0.000293x)+0.000214;
    //    //
    //    Vthrm = 2.0;
    //    //
    //    if(Vthrm > 1.00 as Vthrm > 2.2)
    //    writeSentence("MEDIUM TEMPERATURE READY",0);
    //    else if(Vthrm > 2.78)
    //    {
    //        motorOnCNW();
    //        // turn motor on closing the flue if temperature is above medium
    //    }
    //    else
    //    {
    //        motorOnCCW();
    //        // else turn motor in opposite direction opening the flue
    //    }
    //}
```c
// while((voltage > 2.00 && voltage < 3.2) == 1) { //for high temperature setting
//   unsigned int i = pollADC0();
//   unsigned int j = pollADC1();
//   voltage = (0.000734*i) - 0.018872;
//   Vtherm = (0.000238*j) - 0.008214;
//   Vtherm = 3.0;
//   if(Vtherm < 3.2 && Vtherm > 2.00)
//     writeSentence("HIGH TEMPERATURE READY", 0);
//   else if(Vtherm > 1.85)
//     motorOnCW(); // turn motor on closing the flue if temperature is above high
//   else
//     motorOnCCW(); // else turn motor in opposite direction opening the flue
// }

// unsigned int i = 0;
// PLED = 0x08; // Set P1.3 to output direction to run LED
// for (i = 1; i <= 2; i++) { // repeats words two times
//   writeWord("CONFIG ", i); // show this word once
//   writeWord("READY ", i); // show this word once also
//   writeSentence("SYSF40F449 REPORTING FOR DUTY!", 0);
// }

/********************** initSys() *****************************/
void init_sys(void)
{
   // setup globals
   timer = 0;
   timer_length = 12000 - 1; // max legal value--will be set when timer is activated
   initLCD(); // setup LCD for work
   clearLCD(); // Clear LCD display
   setupADC(); // setup ADC for use
   setupMotor(); // setup motor for use
   NDICL = WDIPN + WDEOHLD; // stop watchdog timer
   _BIS_SR(GIE); // Global Interrupt enable
}

/****************** Timer Functions **************************/

/* This function configures and starts Timer B */
void runtime(void)
{
   TBCTL = TBSEL_1 + CNTL_0 + MC_1 + ID_0; // ACLR, 16 Bit, up mode, div=1
   TBCC0 = 0x010C; // 327 ACLK ticks = -1/100 seconds
   TBCTL0 = CCIE; // TBCC0 interrupt enabled
}
void setup(void)
{
    // This function stops Timer 8 */
    void stoptimer8(void) // (int reset)
    {
        TCCR8 = MC_0; // stop timer
        TCCR8 &= ~OCIE; // TCCR8R interrupt disabled
        /*
        if(reset)
        {
            timer=0;
            min=0;
            sec=0;
        }
        */
    }
    
    /***************************************************************************
    ** setupADC(); *************************************************************/
    void setupADC(void)
    {
        ADC12CTL0 &= ~ENC;
        ADC12CTL0 &= ~ENC;
        PASEL = 0x00; // Enable A/D channel A0 and A1
        ADC12C2S = SHR_2 + REFON + ADC12ON + REF2_5V; // Turn on ADC12, set sampling time, REFERENCE VOLTAGE (set to 2.5V)
        ADC12CTL1 = SHF;
        _delay_cycles(128);
        ADC12CTL1 = ENC; // Enable conversions
        ADC12CTL1 = ENC;
    }
    /***************************************************************************
    ** pollADC0(); ***********************************************************/
    unsigned int pollADC0(void)
    {
        ADC12C2S = ADC12S; // Start conversion
        while ((ADC12IFG & BIT0)!=0) // SET BREAKPOINT HERE
        _NOP();
        return ADC12MEM0;
    }
    /***************************************************************************
    ** pollADC1(); ***********************************************************/
    unsigned int pollADC1(void)
    {
        ADC12C2S = ADC12S; // Start conversion
        while ((ADC12IFG & BIT1)!=0) // SET BREAKPOINT HERE
        _NOP();
        return ADC12MEM1;
    }
    /***************************************************************************
    ** setupMotor(); *************************************************************/
    void setupMotor(void)
    {

PIDIR |= 0x10;
PISO = 0x10;
PINSEL = 0x00;
PRINT = 0x00;
motorOff();
}

/***********************************************************************************/
void motorOnCW(void)
{
  POUT |= 0x30;
}

/***********************************************************************************/
void motorOnCCW(void)
{
  POUT |= 0x30;
}

/*******************************************************************************/
void motorOff(void)
{
  POUT = 0x00;
}

/***********************************************************************************/
void writeNumber(int long number)  // A cool function that moves number right to left
{
  unsigned int 1;
  unsigned int digit;
  char Letter;

clearLCD();

  for (i=1; i<9; i++)
    // Extract each digit in number, put in an integer array, and count total length also
    digit = number%10;
    number = number/10;

  switch(digit)  // pass on the right char value to writeLetter function
  {
    case 0: Letter = '0'; writeLetter(Letter); break;
    case 1: Letter = '1'; writeLetter(Letter); break;
    case 2: Letter = '2'; writeLetter(Letter); break;
    case 3: Letter = '3'; writeLetter(Letter); break;
    case 4: Letter = '4'; writeLetter(Letter); break;
    case 5: Letter = '5'; writeLetter(Letter); break;
    case 6: Letter = '6'; writeLetter(Letter); break;
    case 7: Letter = '7'; writeLetter(Letter); break;
  }
```c
    case 8: Letter = '8'; writeLetter(1,Letter); break;
    case 9: Letter = '9'; writeLetter(1,Letter); break;

    if (number == 0) // when the number has finally been reduced to zero
        break; // break so that LCD doesn't display leading zeroes. E.g. 214 instead of 000214
    shortDelay(2); // remove this delay if you update numbers regularly

    // ******************************************************************** shortDelay ****************
    void shortDelay(int dSpeed) // a very easy to code delay which keeps the processor busy for a small duration of time
    {
        unsigned int iDelay = 0;
        unsigned int kDelay = 0;
        for (kDelay = 1;kDelay < dSpeed * 5 ;kDelay++) // kDelay value can be changed from 10 - 50
        {
            iDelay = 8000;
            // Do not make iDelay more than 40000. Change kDelay instead
            do {iDelay--;} while (iDelay != 0);
        }
    }

    // ******************************************************************** initLCD ****************
    void initLCD(void) // initialize the various registers for LCD to work (codes obtained from sample demos of NSP69PH449)
    {
        FILE_CFG = LCAP18PF; // set load capacitance for 32k xtal
        // Initialize LCD driver (4x8 mode)
        LCCTL = LCD600_7 + LCD4MX + LCDON; // 4x16 LCD, segs16-23 = outputs
        BTCTL = D1_LCD_DIV128; // set LCD frame freq = ACLK
        PSSEL = 0xFFFF; // set Rxx and Cxx pins for LCD
    }

    // ******************************************************************** clearLCD ****************
    void clearLCD(void) // makes the LCD blank
    {
        // Clear LCD memory to Clear display
        unsigned int LCD;
        for (iLCD = 0; iLCD < 15; iLCD++) // clears all 15 LCD memory segments
        {
            LCD[iLCD] = 0;
        }
    }

    // ******************************************************************** writeLetter ****************
    void writeLetter(int position, char letter) // writes a single character on the LCD. User can specify position as well
    {
        // DO NOT PLAY WITH THE CODE BELOW -----------------------------------------------
        if (position == 1) { position = position + 6; } // this is position adjustment for compatibility.
    }
```
```c
else if (position == 2 || position == 3 || position == 4 || position == 5 || position == 6 || position == 7) {
    position = ((position - 2) + 6); // adjust position
```
// writeSentence

void writeSentence(char *word, int scrollForever) { // write out an entire sentence scrolling it right to left
   // sentences must be in upper case

   unsigned int strLength = strlen(word); // variable to store length of the sentence
   unsigned int i; // dummy variable
   unsigned int j; // dummy variable
   unsigned int k; // dummy variable
   char letter_list[75]; // keeps track of characters. Sentence can have upto 74 characters. Do not make too large
   unsigned int position_list[75]; // keeps track of position of the characters
   unsigned int marker = 0; // keeps track of index of the last being displayed character
   unsigned int dispCount = 0; // keep count of how many characters are being displayed
   unsigned int flag = 1; // a normal flag that defines if progress should be stopped

   strLength = strlen(word); // get the length of the sentence

   for (i = 1; i <= strLength; i++) { // put each character in string in a special array called letter_list
      letter_list[i - 1] = word[i - 1];
      position_list[i] = 0; // also, place their relative position values in an array called position_list
   }

   marker = strLength; // marker takes the position of the last character
   position_list[marker] = 1; // set the marker of this position to 1
   dispCount++; // dispCount = 1; meaning we start display with 1 character
   do
      // Do it until all characters are displayed
      for (k = marker; k >= marker - dispCount + 1; k--) // display the first frame
         //...
```c
[ writeLetter(position_list[k], letter_list[k]);
 }

if (dispCount < 7) // update frame count (characters to be displayed during next frame)
{
    dispCount++; }

for (i = marker; i >= marker - dispCount + 1; i--) // shift the relative position values
{
    position_list[i] = position_list[i + 1];
    if (position_list[i] == 0) // shift the marker value
    {
        marker--;   // make sure marker never goes less than zero
    }
}

if (position_list[1] == 2) // when marker has hit maximum index
{
    if (scrollForever == 0)
    {
        flag = 0; clearLCD(); } // adjust flag value to repeat or not
    marker = strLength;    // reset marker to original
    dispCount = 1;        // display length of frame to 1
    for (j = 1; j <= 50; j++) // reset position_list to original
    {
        if (marker != j)
        {
            position_list[j] = 0; }
        else if (marker == j)
        {
            position_list[j] = 1; } // set position_list of marker character to 1
    }
} while (flag == 1);    // function repeats forever if flag remains 1

// -------------------------------------------- writeSentence(--------------------------------------------
void writeWord(const char *word, int repeat_times) // displays a word (upto 7 characters) for specified number of times
// words must be in upper case
{
    unsigned int strLength = 0; // variable to store length of word
    unsigned int i;           // dummy variable
    unsigned int k;           // dummy variable
```
strLen = strlen(word); // get the length of word now

for (k = 1; k <= repeat_times; k++) // repeat display
{  
   for (i = 1; i <= strLen; i++) // display word
   {  
      writeLetter(strLen - i + 1, word[i-1]); // displays each letter in the word
      shortDelay[3]; // software delay
      clearLCD(); // clear the LCD
      shortDelay[2]; // software delay
   }
}

// **************************************************************************
// A short tutorial on using LCD commands effectively

/** // (a) To display battery life indicator (copy and paste the following):
   * writeLetter(1,"*"); // zero battery life
   * shortDelay[6];
   * writeLetter(1,"**"); // low
   * shortDelay[6];
   * writeLetter(1,"*"); // medium
   * shortDelay[6];
   * writeLetter(1,"*"); // full battery life
   * shortDelay[6];
   */

/** // (b) To display + and - signs:
   * writeLetter(1,"+"); // displays plus sign
   * shortDelay[6];
   * writeLetter(1,"-"); // displays negative sign *

/** // (c) To display signed numbers with decimals:
   * writeWord("=18.98",1);  *

/** // (d) To display a number excluding decimals
   * writeNumber(1234567);  *

/** // (e) To display a number including decimals

/** // (f) To display the arrows on LCD:
   * writeLetter(1,">"); // shows top arrow
   * shortDelay[6];
   * writeLetter(1,"<"); // shows bottom arrow
   * shortDelay[6];
   * writeLetter(1,">"); // shows right arrow
   * shortDelay[6];
   * writeLetter(1,"<"); // shows left arrow
   * shortDelay[6]; */
Appendix B

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- RISC Architecture
  - 130 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle multiplier
- Nonvolatile Program and Data Memories
  - 8K Bytes of In-System Self-programmable Flash
    - Endurance: 10,000 Write/Erase Cycles
  - Optional Boot Code Section with Independent Lock bits
  - In-System Programming by On-chip Boot Program
  - True Read-While-Write Operation
  - 512 Bytes EEPROM
    - Endurance: 100,000 Write/Erase Cycles
  - 512 Bytes Internal SRAM
  - Up to 64K Bytes Optional External Memory Space
  - Programming Lock for Software Security
- Peripheral Features
  - One 8-bit Timer/Counter with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Three PWM Channels
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Three Sleep Modes: Idle, Power-down and Standby
- I/O and Packages
  - 35 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, 44-lead PLCC, and 44-pin GQFN/MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega8515L
  - 4.5 - 5.5V for ATmega8515
- Speed Grades
  - 0 - 8 MHz for ATmega8515L
  - 0 - 16 MHz for ATmega8515
Thin Film Platinum RTD's

U.S. Sensor's thin film platinum resistance temperature detectors (Pt-RTD) consist of a thin film platinum deposited on a ceramic substrate. Thin film Pt-RTD's provide cost advantages when compared to wire wound Pt-RTD's because of their lower material cost factor.

Features

- Glass coated platinum element
- Virtually linear relationship between temperature and resistance
- Capable of withstanding temperatures ranging from -50°C to +560°C. Higher temperature ratings are available by special order.
- High accuracy: Resistance and temperature deviation can be controlled to within +0.06% and +0.15°C, a tolerance that corresponds to Class A or DIN EN 60751 or Class 1.2 DIN of DIN 43760

Specifications

- Thermal time constant: 1.5 seconds max. (moving air)
- Dissipation constant: 2mW/°C (moving air)
- Maximum applied current: 1 mA

RTD THIN PLATINUM

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Resistance @ 0°C</th>
<th>DIN 43760 Class</th>
<th>Resistance @ 100°C</th>
<th>TCR ppm/°C</th>
<th>Temp. Dev. @ 50°C</th>
<th>Dim. “L” (40.647)</th>
<th>Dim. “W” (10.648)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFG101A1</td>
<td>100</td>
<td>A</td>
<td>0.05</td>
<td>0.15</td>
<td>3050</td>
<td>0.067</td>
<td>0.110</td>
</tr>
<tr>
<td>PFG101B1</td>
<td>100</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3050</td>
<td>0.067</td>
<td>0.110</td>
</tr>
<tr>
<td>PFG101C1</td>
<td>100</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3050</td>
<td>0.067</td>
<td>0.110</td>
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<tr>
<td>PFG101A1</td>
<td>500</td>
<td>A</td>
<td>0.06</td>
<td>0.13</td>
<td>3050</td>
<td>0.079</td>
<td>0.118</td>
</tr>
<tr>
<td>PFG101B1</td>
<td>500</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3050</td>
<td>0.079</td>
<td>0.118</td>
</tr>
<tr>
<td>PFG101C1</td>
<td>500</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3050</td>
<td>0.079</td>
<td>0.118</td>
</tr>
<tr>
<td>PFG102A1</td>
<td>1000</td>
<td>A</td>
<td>0.06</td>
<td>0.15</td>
<td>3050</td>
<td>0.079</td>
<td>0.110</td>
</tr>
<tr>
<td>PFG102B1</td>
<td>1000</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3050</td>
<td>0.079</td>
<td>0.118</td>
</tr>
<tr>
<td>PFG102C1</td>
<td>1000</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3050</td>
<td>0.079</td>
<td>0.118</td>
</tr>
<tr>
<td>PFG102A2</td>
<td>1000</td>
<td>A</td>
<td>0.12</td>
<td>0.30</td>
<td>3750</td>
<td>0.079</td>
<td>0.110</td>
</tr>
<tr>
<td>PFG102B2</td>
<td>1000</td>
<td>B</td>
<td>0.24</td>
<td>0.60</td>
<td>3750</td>
<td>0.079</td>
<td>0.110</td>
</tr>
<tr>
<td>PFG102C2</td>
<td>1000</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3750</td>
<td>0.079</td>
<td>0.110</td>
</tr>
</tbody>
</table>

Home

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Fax: 714-696-1220
Email: sales@usensor.com
TECHNICAL DATA

MQ-7 GAS SENSOR

FEATURES
- High sensitivity to carbon monoxide
- Stable and long life

APPLICATION
They are used in gas detecting equipment for carbon monoxide (CO) in family and industry or car.

SPECIFICATIONS

A. Standard work condition

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>technical condition</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vc</td>
<td>circuit voltage</td>
<td>5V±0.1</td>
<td>Ac or Dc</td>
</tr>
<tr>
<td>Vth(H)</td>
<td>Heating voltage (high)</td>
<td>5V±0.1</td>
<td>Ac or Dc</td>
</tr>
<tr>
<td>Vth(L)</td>
<td>Heating voltage (low)</td>
<td>1.4V±0.1</td>
<td>Ac or Dc</td>
</tr>
<tr>
<td>RL</td>
<td>Load resistance</td>
<td>Can adjust</td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>Heating resistance</td>
<td>33 Ω ±5%</td>
<td>Room temperature</td>
</tr>
<tr>
<td>TH(h)</td>
<td>Heating time (high)</td>
<td>60±1 seconds</td>
<td></td>
</tr>
<tr>
<td>TH(l)</td>
<td>Heating time (low)</td>
<td>90±1 seconds</td>
<td></td>
</tr>
<tr>
<td>PH</td>
<td>Heating consumption</td>
<td>Less than 300μaW</td>
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</tbody>
</table>

b. Environment conditions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameters</th>
<th>Technical conditions</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>Using temperature</td>
<td>-20ºC-50ºC</td>
<td></td>
</tr>
<tr>
<td>T0s</td>
<td>Storage temperature</td>
<td>-20ºC-50ºC</td>
<td>Advice using scope</td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity</td>
<td>Less than 95%RH</td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>Oxygen concentration</td>
<td>21% (stand condition)</td>
<td>the oxygen concentration can affect the sensitivity characteristic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum value is over 2%</td>
<td></td>
</tr>
</tbody>
</table>

c. Sensitivity characteristic

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameters</th>
<th>Technical parameters</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs</td>
<td>Surface resistance of sensitive body</td>
<td>2-20k</td>
<td>In 100ppm Carbon Monoxide</td>
</tr>
<tr>
<td>a (300/100ppm)</td>
<td>Concentration slope rate</td>
<td>Less than 0.5</td>
<td>Rs (300ppm)/Rs(100ppm)</td>
</tr>
<tr>
<td></td>
<td>Standard working condition</td>
<td>Temperature -20ºC±2ºC relative humidity 65%±5% RL: 10kΩ±5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vc:5V±0.1V</td>
<td>VH:5V±0.1V</td>
</tr>
<tr>
<td></td>
<td>Preheat time</td>
<td>No less than 48 hours</td>
<td>Detecting range: 20ppm-2000ppm carbon monoxide</td>
</tr>
</tbody>
</table>

D. Structure and configuration, basic measuring circuit

Structure and configuration of MQ-7 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro Al2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 have
TECHNICAL DATA MQ-135 GAS SENSOR

FEATURES
Wide detecting scope
Fast response and High sensitivity
Stable and long life
Simple drive circuit

APPLICATION
They are used in air quality control equipments for buildings/offices, are suitable for detecting of NH3, NOx, alcohol, Benzene, smoke, CO2, etc.

SPECIFICATIONS

A. Standard work condition

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>Technical condition</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>Circuit voltage</td>
<td>5V±0.1</td>
<td>AC OR DC</td>
</tr>
<tr>
<td>Vh</td>
<td>Heating voltage</td>
<td>3V±0.1</td>
<td>ACOR DC</td>
</tr>
<tr>
<td>Rl</td>
<td>Lead resistance</td>
<td>can adjust</td>
<td></td>
</tr>
<tr>
<td>Rk</td>
<td>Master resistance</td>
<td>33Ω±5%</td>
<td>Room Temp</td>
</tr>
<tr>
<td>Pn</td>
<td>Heating consumption</td>
<td>less than 500mW</td>
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</table>

B. Environment condition

<table>
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<th>Symbol</th>
<th>Parameter name</th>
<th>Technical condition</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>Ta</td>
<td>Time Temp</td>
<td>-10±45℃</td>
<td></td>
</tr>
<tr>
<td>Ts</td>
<td>Storage Temp</td>
<td>-20±70℃</td>
<td></td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity</td>
<td>less than 95%RH</td>
<td></td>
</tr>
<tr>
<td>SO2</td>
<td>Oxygen concentration</td>
<td>21%(standard condition)</td>
<td>Oxygen concentration can affect sensitivity minimum value is over 2%</td>
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</table>

C. Sensitivity characteristic

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>Technical parameter</th>
<th>Remarks 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs</td>
<td>Sensing Resistance</td>
<td>100Ω-3000Ω</td>
<td>(100ppm NH3)</td>
</tr>
<tr>
<td>G</td>
<td>Concentration</td>
<td>a=0.65</td>
<td>Slope rate</td>
</tr>
<tr>
<td>200/50</td>
<td>NH3</td>
<td>Temp: 20±42℃</td>
<td>Vc: 3V±0.1</td>
</tr>
</tbody>
</table>

D. Structure and configuration, basic measuring circuit

![Fig. 1](image1)

![Fig. 2](image2)

Structure and configuration of MQ-135 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro Al2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive
components. The enveloped MQ-135 have 6 pin, 4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown in Fig 2.

E. Sensitivity characteristic curve

Fig 2 sensitivity characteristics of the MQ-135

![MQ-135 Sensitivity Curve](image)

Fig 3 is shows the typical sensitivity characteristics of the MQ-135 for several gases. in their: Temp 200℃

Humidity: 65%RH

O₂ concentration: 21%

R₀=20kΩ

R₆: sensor resistance at 100ppm of NH₃ in the clean air.

R₇: sensor resistance at various concentrations of gases.

![Sensitivity Curve Diagram](image)

Fig 4 is shows the typical dependence of the MQ-135 on temperature and humidity.

R₀: sensor resistance at 100ppm of NH₃ in air at 33%RH and 20 degree.

R₇: sensor resistance at 100ppm of NH₃ at different temperatures and humidities.

**SENSITIVITY ADJUSTMENT**

Resistance value of MQ-135 is difference to various kinds and various concentration gases. So, when using this components, sensitivity adjustment is very necessary. We recommend that you calibrate the detector for 100ppm NH₃ or 500ppm Alcohol concentration in air and use value of Lead resistance( R₀) about 20 KΩ to 10 KΩ to 47 KΩ).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

![MQ-135 Components](image)
Features
- High Intensity.
- Low Power Consumption.
- Popular T-1 3/4 Diameter Package.
- General Purpose Leads.
- Reliable and Rugged.
- Available on Tape and Reel.

Description
The Bright Red source color devices are made with Gallium Phosphide Red Light Emitting Diode.
The Green source color devices are made with Gallium Phosphide Green Light Emitting Diode.
The High Efficiency Red and Orange source color devices are made with Gallium Arsenide Phosphide on Gallium Phosphide Orange Light Emitting Diode.
The Yellow source color devices are made with Gallium Arsenide Phosphide on Gallium Phosphide Yellow Light Emitting Diode.
The Pure Orange source color devices are made with Gallium Arsenide Phosphide on Gallium Phosphide Pure Orange Light Emitting Diode.
The Pure Green source color devices are made with Gallium Phosphide Pure Green Light Emitting Diode.

Package Dimensions

Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.25(0.01) unless otherwise noted.
3. Lead spacing is measured where the lead emerges package.
4. Specifications are subject to change without notice.
## Selection Guide

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Dio</th>
<th>Lens Type</th>
<th>I&lt;sub&gt;r&lt;/sub&gt; (mod) @ 10 mA</th>
<th>Viewing Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>L39HD</td>
<td>BRIGHT RED (GaP)</td>
<td>RED DIFFUSED</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>L39D</td>
<td>RED DIFFUSED</td>
<td>8</td>
<td>25</td>
<td>60°</td>
</tr>
<tr>
<td>L39T</td>
<td>HIGH EFFICIENCY RED (GaAsP:GaP)</td>
<td>RED TRANSPARENT</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>L39EC</td>
<td>WATER CLEAR</td>
<td>30</td>
<td>80</td>
<td>30°</td>
</tr>
<tr>
<td>L39ED</td>
<td>ORANGE (GaAsP:GaP)</td>
<td>ORANGE DIFFUSED</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>L39GD</td>
<td>GREEN DIFFUSED</td>
<td>5</td>
<td>20</td>
<td>60°</td>
</tr>
<tr>
<td>L39GT</td>
<td>GREEN (GaP)</td>
<td>GREEN TRANSPARENT</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>L39GC</td>
<td>WATER CLEAR</td>
<td>20</td>
<td>60</td>
<td>30°</td>
</tr>
<tr>
<td>L39YD</td>
<td>YELLOW DIFFUSED</td>
<td>5</td>
<td>20</td>
<td>60°</td>
</tr>
<tr>
<td>L39YT</td>
<td>YELLOW (GaAsP:GaP)</td>
<td>YELLOW TRANSPARENT</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>L39YC</td>
<td>WATER CLEAR</td>
<td>20</td>
<td>40</td>
<td>30°</td>
</tr>
<tr>
<td>L39ND</td>
<td>ORANGE DIFFUSED</td>
<td>12</td>
<td>30</td>
<td>60°</td>
</tr>
<tr>
<td>L39NT</td>
<td>PURE ORANGE (GaAsP:GaP)</td>
<td>ORANGE TRANSPARENT</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>L39NC</td>
<td>WATER CLEAR</td>
<td>50</td>
<td>80</td>
<td>30°</td>
</tr>
<tr>
<td>L39PGD</td>
<td>GREEN DIFFUSED</td>
<td>2</td>
<td>5</td>
<td>60°</td>
</tr>
<tr>
<td>L39PGT</td>
<td>PURE GREEN (GaP)</td>
<td>GREEN TRANSPARENT</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>L39PGC</td>
<td>WATER CLEAR</td>
<td>5</td>
<td>10</td>
<td>30°</td>
</tr>
</tbody>
</table>

Note:
1. Viewing Angle is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.

## Absolute Maximum Ratings at T<sub>a</sub>=25°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bright Red</th>
<th>High Efficiency Red</th>
<th>Orange</th>
<th>Green</th>
<th>Yellow</th>
<th>Pure Orange</th>
<th>Pure Green</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power dissipation</td>
<td>120</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>mW</td>
</tr>
<tr>
<td>DC Forward Current [1]</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Forward Current [1]</td>
<td>120</td>
<td>160</td>
<td>160</td>
<td>140</td>
<td>140</td>
<td>145</td>
<td>135</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
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<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Operating/Storage Temperature</td>
<td>-40°C to +85°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Soldering Temperature [2]</td>
<td>260°C For 5 Seconds</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. Allow below package bars.
## Electrical / Optical Characteristics at $T_a=25^\circ C$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Device</th>
<th>Typ.</th>
<th>Min.</th>
<th>Max.</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{pe}$</td>
<td>Peak Wavelength</td>
<td>Bright Red</td>
<td>700</td>
<td>627</td>
<td>627</td>
<td>nm</td>
<td>$I_F=20mA$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Efficiency Red</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Pure Orange</td>
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<tr>
<td></td>
<td></td>
<td>Pure Green</td>
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</tr>
<tr>
<td>$\lambda_{D}$</td>
<td>Dominant Wavelength</td>
<td>Bright Red</td>
<td>660</td>
<td>625</td>
<td>625</td>
<td>nm</td>
<td>$I_F=20mA$</td>
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<td>Pure Green</td>
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</tr>
<tr>
<td>$\Delta\lambda_{1/2}$</td>
<td>Spectral Line Width</td>
<td>Bright Red</td>
<td>45</td>
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<td>45</td>
<td>nm</td>
<td>$I_F=20mA$</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Pure Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C$</td>
<td>Capacitance</td>
<td>Bright Red</td>
<td>40</td>
<td>15</td>
<td>15</td>
<td>pF</td>
<td>$V_T=0V$, $f=1VHz$</td>
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<td></td>
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<td>Yellow</td>
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<td></td>
<td></td>
<td>Pure Orange</td>
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<td></td>
<td></td>
<td>Pure Green</td>
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</tr>
<tr>
<td>$V_F$</td>
<td>Forward Voltage</td>
<td>Bright Red</td>
<td>2.25</td>
<td>2.0</td>
<td>2.0</td>
<td>V</td>
<td>$I_F=20mA$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Efficiency Red</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orange</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green</td>
<td></td>
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<td></td>
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<td>Yellow</td>
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<td></td>
<td></td>
<td>Pure Orange</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
<td>Pure Green</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$I_R$</td>
<td>Reverse Current</td>
<td>All</td>
<td>10</td>
<td></td>
<td></td>
<td>uA</td>
<td>$V_T=5V$</td>
</tr>
</tbody>
</table>

![Relative Intensity vs. Wavelength Graph](image)

**SPEC NO:** C0A0704  
**REV NO:** V.1  
**DATE:** NOV/12/2001  
**PAGE:** 3 OF 7  
**APPROVED:** J. Lu  
**CHECKED:**  
**DRAWN:** Z.W. Tan
Kingbright

T-1 3/4 (3mm) SOLID STATE LAMP

Part Number: WP1130GCK  Green

Features
- Low power consumption.
- Popular T-1 3/4 diameter package.
- General purpose leads.
- Malleable and rugged.
- Long life - solid state reliability.
- Available on tape and reel.
- RoHS compliant.

Description
The Green source color devices are made with AlGaNp on GaAs substrate Light Emitting Diode.

Package Dimensions

Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ±0.250 (0.01") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. The specifications, characteristics and technical data described in the datasheet are subject to change without prior notice.

SPEC NO: DSAF2399  REV NO: V6  DATE: MAR/15/2011  PAGE: 1 OF 6
### Selection Guide

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Diode</th>
<th>Lens Type</th>
<th>$I_v$ (max) [2] $@20mA$</th>
<th>Viewing Angle [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP7112E051X</td>
<td>Green (AlGaNp)</td>
<td>Water Clear</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. $\theta$ is the angle from optical centerline where the luminous intensity is 1/2 of the optical peak value.
2. Luminous intensity, Luminous Flux: $\pm 15\%$

### Electrical / Optical Characteristics at $T_A=22^\circ$C

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Device</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{peak}}$</td>
<td>Peak Wavelength</td>
<td>Green</td>
<td>574</td>
<td>nm</td>
<td>$I=20mA$</td>
<td></td>
</tr>
<tr>
<td>$A_D$ [1]</td>
<td>Dominant Wavelength</td>
<td>Green</td>
<td>570</td>
<td>nm</td>
<td>$I=20mA$</td>
<td></td>
</tr>
<tr>
<td>$\Delta \lambda/2$</td>
<td>Spectral Line Half-width</td>
<td>Green</td>
<td>20</td>
<td>nm</td>
<td>$I=20mA$</td>
<td></td>
</tr>
<tr>
<td>$C$</td>
<td>Capacitance</td>
<td>Green</td>
<td>15</td>
<td>pF</td>
<td>$V=5V, f=1MHz$</td>
<td></td>
</tr>
<tr>
<td>$V_{\text{R}}$ [2]</td>
<td>Forward Voltage</td>
<td>Green</td>
<td>2.1</td>
<td>2.5</td>
<td>V</td>
<td>$I=20mA$</td>
</tr>
<tr>
<td>$I_R$</td>
<td>Reverse Current</td>
<td>Green</td>
<td>10</td>
<td>uA</td>
<td>$V_R=5V$</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Wavelength: $\pm 5\%$
2. Forward Voltage: $\pm 2\%$

### Absolute Maximum Ratings at $T_A=25^\circ$C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Green</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power dissipation</td>
<td>75</td>
<td>mW</td>
</tr>
<tr>
<td>DC Forward Current</td>
<td>30</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Forward Current [1]</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>6</td>
<td>V</td>
</tr>
<tr>
<td>Operating/Storage Temperature</td>
<td>-40°C to +85°C</td>
<td></td>
</tr>
<tr>
<td>Lead Solder Temperature [2]</td>
<td>260°C for 3 Seconds</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. 100 Duty Cycle, 3.1ms Pulse Width.
2. 2mm below package base.
3. 1.9mm below package base.
PRECAUTIONS

1. The lead pitch of the LED must match the pitch of the mounting holes on the PCB during component placement. Lead-forming may be required to insure the lead pitch matches the hole pitch. Refer to the figure below for proper lead forming procedures. (Fig. 1)

Fig.1

"○ " Correct mounting method "×" Incorrect mounting method

2. When soldering wire to the LED, use individual heat-shrink tubing to insulate the exposed leads to prevent accidental contact short-circuit. (Fig.2)

3. Use stand-offs (Fig.3) or spacers (Fig.4) to securely position the LED above the PCB.

Fig. 2  Fig. 3  Fig. 4

4. Maintain a minimum of 2mm clearance between the base of the LED lens and the first lead bend. (Fig. 5 and 6)

5. During lead forming, use tools or jigs to hold the leads securely so that the bending force will not be transmitted to the LED lens and its internal structures. Do not perform lead forming once the component has been mounted onto the PCB. (Fig. 7)
6. Do not bend the leads more than twice. (Fig. 8)

7. During soldering, component covers and holders should leave clearance to avoid placing damaging stress on the LED during soldering.

8. The tip of the soldering iron should never touch the lens epoxy.
9. Through-hole LEDs are incompatible with reflow soldering.
10. If the LED will undergo multiple soldering passes or face other processes where the part may be subjected to intense heat, please check with Kingbright for compatibility.
11. Recommended Wave Soldering Profile for Kingbright Thru-Hole Products

NOTES:
1. Recommend the wave temperature 245°C~260°C. The maximum soldering temperature should be less than 260°C.
2. Do not apply stress on epoxy resins when temperature is over 85°C.
3. The soldering profile apply to the lead free soldering (Sn/Cu/Ag alloy).
4. During wave soldering, the PCB top-surface temperature should be kept below 100°C.
5. No more than once.
1-Watt SMD 6mm (120° Viewing Angle)

OVSPW1BCR4
- Robust, energy-efficient design with long operating life
- Low thermal resistance—10°C/W
- Exceptional spatial uniformity
- Optional optics to suit application
- High Lumens output

The OVSPW1BCR4 is an energy-efficient packaged LED source that offers high luminance, and a long operating lifespan. This device offers a 120° viewing angle and an ultra-low profile (1.5mm) making it highly suitable for conventional lighting and specialized applications. Optional optics are offered to suit application. Please contact OPTEK for more information.

Applications
- Automotive exterior and interior lighting
- Architectural indoor and outdoor lighting
- General lighting
- Electronic signs and signals

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Viewing Angle</th>
<th>Emitted Color</th>
<th>Typical Luminous Flux (Im)</th>
<th>Typical On-Axis intensity (cd)</th>
<th>Lens Color</th>
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</thead>
<tbody>
<tr>
<td>OVSPW1BCR4</td>
<td>120°</td>
<td>White</td>
<td>90</td>
<td>na</td>
<td>Water Clear</td>
</tr>
</tbody>
</table>

Dimensions are in mm (unless noted otherwise) 

DO NOT LOOK DIRECTLY AT LED WITH UNSHIELDED EYES OR DAMAGE TO RETINA MAY OCCUR.

OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.
1-Watt SMD 6mm
OVSPW1BCR4

Absolute Maximum Ratings $T_a = 25^\circ C$

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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<td>4.0</td>
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<td>Luminous Flux</td>
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<td>90</td>
<td>113</td>
<td>lm</td>
</tr>
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<td>$\mu A$</td>
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<td></td>
<td>deg</td>
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NOTES:
1. Pulse Width $t = 1\mu s$, Duty cycle = 0.1
2. Thermal conductive = 10 $\text{W/}^\circ\text{C}$

Optical and Electrical Characteristics $(I_p = 350\text{mA}, T_a = 25^\circ C)$
1-Watt SMD 6mm
OVSPW1BCR4

Standard Bins (Ie = 350 mA)  OVSPW1BCR4 (White)
LEDs are sorted to luminous flux (\(\Phi\)), chromaticity coordinates, and correlated color temperature (CCT) bins shown. Orders may be filled with any or all bins contained as below.

### White CCT Bin Structure

<table>
<thead>
<tr>
<th>Color Bin</th>
<th>Minimum CCT (K)</th>
<th>Maximum CCT (K)</th>
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<td>5500</td>
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<td>7000</td>
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<tr>
<td>Y</td>
<td>7000</td>
<td>10000</td>
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<table>
<thead>
<tr>
<th>(\Phi)</th>
<th>Luminous Flux (lm)</th>
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<td>T2</td>
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<td>U3</td>
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<tr>
<td>XP</td>
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<tr>
<td>UO</td>
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<td>0.344</td>
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</table>
1-Watt SMD 6mm
OVSPW1BCR4

Typical Electro-Optical Characteristics Curves

Relative Luminous Intensity vs. Forward Current

Flux vs. Forward Current

Forward Current vs. Forward Voltage

Relative Spectral Emission

Maximum Luminous Current

Forward Current vs. Radiant Temperature

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OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.
Radiation Pattern

Solder Pad Design
Note: Metal core circuit board (MCPCB) is highly recommended for high density applications. Please consult sales and marketing for additional information.

Polarity varies with color. Please see Page 1.
Recommended Sn-Pb IR-Reflow Soldering Profile.

Classification Reflow Profile (JEDEC J-STD-020C)

Recommended Pb Free IR-Reflow Soldering Profile.

Classification Reflow Profile (JEDEC J-STD-020C)
Taping and Orientation
Loaded quantity 2000 pieces per reel

Reel Dimensions (13 inch)
Moisture Resistant Packaging

Label → Aluminum Moisture-proof Bag → Desiccant → Bar Code Label
1-Watt SMD 6mm (120° Viewing Angle)

OVSPW1BCR4
- Robust energy-efficient design with long operating life
- Low thermal resistance—10°C/W
- Exceptional spatial uniformity
- Optional optics to suit application
- High Lume output

The OVSPW1BCR4 is an energy-efficient packaged LED source that offers high luminance, and a long operating lifespan. This device offers a 120° viewing angle and an ultra-low profile (1.5mm) making it highly suitable for conventional lighting and specialized applications. Optional optics are offered to suit application. Please contact OPTEK for more information.

Applications
- Automotive exterior and interior lighting
- Architectural indoor and outdoor lighting
- General lighting
- Electronic signs and signals

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Viewing Angle</th>
<th>Emitted Color</th>
<th>Typical Luminous Flux (lm)</th>
<th>Typical On-Axis Intensity (lx)</th>
<th>Lens Color</th>
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</thead>
<tbody>
<tr>
<td>OVSPW1BCR4</td>
<td>120°</td>
<td>White</td>
<td>90</td>
<td>150</td>
<td>Water Clear</td>
</tr>
</tbody>
</table>

DO NOT LOOK DIRECTLY AT LED WITH UNHIELDED EYES OR DAMAGE TO RETINA MAY OCCUR.

OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.
1-Watt SMD 6mm
OVSPW1BCR4

Absolute Maximum Ratings $T_a=25^\circ C$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>DC Forward Current</td>
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<tr>
<td>Peak Pulsed Forward Current$^1$</td>
<td>1000mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>Not designed for reverse bias</td>
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<tr>
<td>Junction Temperature$^2$</td>
<td>125°C</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>1200mW</td>
</tr>
<tr>
<td>Storage and Operating Temperature</td>
<td>-40° to +100 °C</td>
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<tr>
<td>ESD Threshold (HBM)</td>
<td>2000V</td>
</tr>
</tbody>
</table>

Notes:
1. Rise with $t = 10\mu s$, Duty cycle $= 0.1$
2. Thermal conductivity $= 15 \text{ W/K}$

Optical and Electrical Characteristics ($I_e = 350 \text{ mA}, T_a = 25^\circ C$)

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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<tr>
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<td>Luminous Flux</td>
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<td>90</td>
<td>113</td>
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<tr>
<td>$I_r$</td>
<td>Reverse Current</td>
<td>——</td>
<td>10</td>
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<td>$\mu$A</td>
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<tr>
<td>20%</td>
<td>50% Power Angle</td>
<td>——</td>
<td>120</td>
<td>——</td>
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</tbody>
</table>
Standard Bins (I = 350 mA) OVSPW1BCR4 (White)
LEDs are sorted to luminous flux (Φ), chromaticity coordinates, and correlated color temperature (CCT) bins shown. Orders may be filled with any or all bins contained as below.

### White CCT Bin Structure

<table>
<thead>
<tr>
<th>Color Bin</th>
<th>Minimum CCT (K)</th>
<th>Maximum CCT (K)</th>
</tr>
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<tbody>
<tr>
<td>U</td>
<td>4500</td>
<td>5000</td>
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<tr>
<td>V</td>
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<table>
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<th>Φ</th>
<th>Luminous Flux (lm)</th>
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<tbody>
<tr>
<td>Bin</td>
<td>Min</td>
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<tr>
<td>T2</td>
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OPTEK Technology Inc. --- 1645 Wallas Drive, Carrollton, Texas 75010
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Issue A, 10-01

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<table>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Typical Electro-Optical Characteristics Curves

- Relative luminous intensity vs. forward current
- Flux vs. forward current
- Forward current vs. forward voltage
- Relative Spectra Emission
- Maximum Permissible Current

OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.

OPTEK Technology Inc. — 1645 Willow Drive, Carrollton, Texas 75006
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Page 5 of 9
1-Watt SMD 6mm
OVSPW1BCR4

Radiation Pattern

Solder Pad Design
Note: Metal core circuit board (MCPCB) is highly recommended for high density applications. Please consult sales and marketing for additional information.

Polarity varies with color. Please see Page 1.
Recommended Sn-Pb IR-Reflow Soldering Profile.

Recommended Pb Free IR-Reflow Soldering Profile.

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OPTEK Technology Inc. — 1545 Hazard Drive, Carrollton, Texas 75006
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1-Watt SMD 6mm
OVSPW1BCR4

Taping and Orientation
Loaded quantity 2000 pieces per reel

Reel Dimensions (13 inch)

OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.
Moisture Resistant Packaging

Label → Aluminum Moisture-proof Bag → Desiccant → Bar Code Label
M1N10

Specifications

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<tr>
<th>Model</th>
<th>Operating Voltage (V)</th>
<th>Rated Voltage (V)</th>
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<th>No Load Current (mA)</th>
<th>Rated Load</th>
<th>Starting Torque (cm)</th>
<th>Shaft Length (mm)</th>
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Characteristics

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Performance Specifications

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<th>25°C</th>
<th>50°C</th>
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<tr>
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<tr>
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<td>68</td>
<td>75</td>
</tr>
<tr>
<td>I_max (Amps)</td>
<td>8.5</td>
<td>8.4</td>
</tr>
<tr>
<td>V_max (Volts)</td>
<td>15.4</td>
<td>17.5</td>
</tr>
<tr>
<td>Module Resistance (Ohms)</td>
<td>1.50</td>
<td>1.80</td>
</tr>
</tbody>
</table>

Performance curves on page 2

Copyright HB Corporation. HB reserves the right to change these specifications without notice.
Ceramic Material: Alumina (Al₂O₃)
Solder Construction: 138°C, Bismuth Tin (BiSn)

Size table:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>40</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Operating Tips

- Max. Operating Temperature: 138°C
- Do not exceed I_max or V_max when operating module.
- Life expectancy: 200,000 hours
- Please consult HB for moisture protection options (sealing).
- Failure rate based on long term tests: 0.2%.
UNITRODE

bq2054
Lithium Ion Fast-Charge IC

Features
► Safe charge of Lithium ion battery packs
► Voltage-regulated current-limited charging
► Fast charge terminated by selectable minimum current; safety backup termination at maximum time
► Charging continuously qualified by temperature and voltage limits
► Pulse-width modulation control ideal for high-efficiency switching-mode power conversion
► Direct LED control outputs display charge status and fault conditions

General Description
The bq2054 Lithium Ion Fast-Charge IC is designed to optimize charging of lithium ion (Li-ion) chemistry batteries. A flexible pulse-width modulation regulator allows the bq2054 to control voltage and current during charging. The regulator frequency is set by an external capacitor for design flexibility. The switch-mode design keeps power dissipation to a minimum.

The bq2054 monitors battery temperature using an external thermometer for charge qualification. Charging begins when power is applied or on battery insertion.

For safety, the bq2054 inhibits charging until the battery voltage and temperature are within configured limits. If the battery voltage is less than the low-voltage threshold, the bq2054 provides low-current conditioning of the battery.

A constant current-charging phase replenishes up to 70% of the charge capacity and a voltage-regulated phase returns the battery to full. The charge cycle terminates when the charging current falls below a user-selectable current limit. For safety, charging terminates after maximum time and is suspended if the temperature is outside the preconfigured limits.

The bq2054 provides status indicators of all charger stages and faults for accurate determination of the battery and charge system conditions.

Pin Connections

Pin Names

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>Time-out programming input</td>
<td></td>
</tr>
<tr>
<td>VIN</td>
<td>Battery voltage input</td>
<td></td>
</tr>
<tr>
<td>VCC</td>
<td>5.0V±1% power</td>
<td></td>
</tr>
<tr>
<td>VCOM</td>
<td>Voltage loop comp input</td>
<td></td>
</tr>
<tr>
<td>ICOMP</td>
<td>Current loop comp input</td>
<td></td>
</tr>
<tr>
<td>E25</td>
<td>Minimum current termination select input</td>
<td></td>
</tr>
<tr>
<td>SNS</td>
<td>Sense resistor input</td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>Temperature sense input</td>
<td></td>
</tr>
<tr>
<td>TPWM</td>
<td>Regulator timebase input</td>
<td></td>
</tr>
<tr>
<td>LEDn</td>
<td>Charge status output n</td>
<td></td>
</tr>
<tr>
<td>LCOM</td>
<td>Common LED output</td>
<td></td>
</tr>
<tr>
<td>Vss</td>
<td>System ground</td>
<td></td>
</tr>
<tr>
<td>VDD</td>
<td>5.0V±1% power</td>
<td></td>
</tr>
<tr>
<td>MOD</td>
<td>Modulation control output</td>
<td></td>
</tr>
<tr>
<td>LEDo</td>
<td>Charge status output o</td>
<td></td>
</tr>
<tr>
<td>DSEL</td>
<td>Display select input</td>
<td></td>
</tr>
</tbody>
</table>
Pin Descriptions

TM  Time-out programming input
This input sets the maximum charge time. The resistor and capacitor values are determined using Equation 5. Figure 7 shows the resistor/capacitor connection.

ICTL  Inrush current control output
ICTL is driven low during the fault or charge-complete status of the chip. It is used to disconnect the capacitor across the battery pack terminals, preventing small currents from tripping overcurrent protection features in the pack when a new battery is inserted.

BAT  Battery voltage input
BAT is the battery voltage sense input. This potential is generally developed using a high-impedance resistor divider network connected between the positive and the negative terminals of the battery. See Figure 4 and Equation 1.

VCOMP  Voltage loop compensation input
This input uses an external E-C network for voltage loop stability.

IOUT  Minimum current termination select
This three-state input is used to set fuse for fast-charge termination. See Table 2.

ICOMP  Current loop compensation input
This input uses an external E-C network for current loop stability.

SNS  Charging current sense input
Battery current is sensed via the voltage developed on this pin by an external sense resistor. This, connected in series with the negative terminal of the battery pack, can be determined using Equation 6.

TB  Temperature sense input
This input is used to monitor battery temperature. An external resistor divider network sets the lower and upper temperature thresholds. See Figures 6 and Equations 3 and 4.

TPWM  Regulation timebase input
This input uses an external timing capacitor to ground to set the pulse-width modulation (PWM) frequency. See Equation 7.

LCOMP  Common LED output
Common output for LED1-3. This output is in a high-impedance state during initialization to read programming input on J36.

MOD  Current-switching control output
MOD is a pulse-width modulated push/pull output that is used to control the charging current to the battery. MOD switches high to enable current flow and low to inhibit current flow.

LED1, LED2, LED3  Charger display status 1-3 outputs
These charger status output drivers are for the direct drive of the LED display. Display modes are shown in Table 1. These outputs are tri-state during initialization so that J36 can be read.

DSSEL  Display select input
This three-level input controls the LED1-3 charge display modes. See Table 1.

VCC  Vcc supply
2.8V ± 10% power

VSS  Ground
bq2054

Charge Algorithm

The bq2054 uses a two-phase fast charge algorithm. In phase 1, the bq2054 regulates constant current: \( I_{\text{MAX}} \) until \( V_{\text{CELL}} = V_{\text{MAX}} \). The bq2054 then transitions to phase 2 and regulates constant voltage \( V_{\text{CELL}} = V_{\text{REG}} \) until the charging current falls below the programmed low threshold. The charging current must remain below \( I_{\text{MAX}} \) for 120 ± 40ms before a valid fast charge termination is detected. Fast charge then terminates, and the bq2054 enters the Charge Complete state. See Figures 1 and 2.

Charge Qualification

The bq2054 starts a charge cycle when power is applied while a battery is present or when a battery is inserted. Figure 2 shows the state diagram for pre-charge qualification and temperature monitoring. The bq2054 first checks that the battery temperature is within the allowed, user-configurable range. If the temperature is out of range, the bq2054 enters the Charge Pending state and waits until the battery temperature is within the allowed range. Charge Pending is indicated by LED flashing.

Thermal monitoring continues throughout the charge cycle, and the bq2054 enters the Charge Pending state when the temperature is out of range. (There is one exception: if the bq2054 is in the Fault state, the out-of-range temperature is not recognized until the bq2054 leaves the Fault state.) All timers are suspended (but not reset) while the bq2054 is in Charge Pending. When the temperature comes back into range, the bq2054 returns to the point in the charge cycle where the out-of-range temperature was detected.

When the temperature is valid, the bq2054 then regulates current to \( I_{\text{MAX}} \) (or \( I_{\text{MAX}} \)). After an initial hold-off period (which prevents the chip from reacting to transient voltage spikes that may occur when charge current is first applied), the chip begins monitoring \( V_{\text{CELL}} \). If \( V_{\text{CELL}} \) does not rise to at least \( V_{\text{REG}} \) before the expiration of the time-out limit (e.g., the cell has failed short), the bq2054 enters the Fault state. If \( V_{\text{CELL}} \) is achieved before expiration of the time limit, the chip begins fast charging.

Once in the Fault state, the bq2054 waits until \( V_{\text{CELL}} \) is cycled or a new battery insertion is detected. It then starts a new charge cycle and begins the qualification process again.

Figure 1. bq2054 Charge Algorithm
Figure 2. bq2054 State Diagram
Charge Status Display

Charge status is communicated by the LED driver output (LED1-LED3). Three display modes are available in the bq2054: the user selects a display mode by configuring pin DSEL. Table 1 shows the three display modes.

The bq2054 does not distinguish between an over-voltage fault and a "battery absent" condition. The bq2054 enters the fault state, communicated by turning on LED2, whenever the battery is absent. The bq2054, therefore, gives an indication that the charger is on even when no battery is in place to be charged.

Configuring the Display Mode and I_MIN

DSEL/LD2 is a bi-directional pin with two functions; it is an LED driver pin as an output and a programming pin as an input. The selection of pull-up, pull down, or no pull resistor programs the display mode on DSEL per Table 1. The bq2054 latches the programming data stored on the DSEL input when any one of the following three events occur:

1. Voltages are a valid level.
2. The bq2054 leaves the Fault state.
3. The bq2054 detects battery insertion.

The LEDs go blank for approximately 750ms (typical) while new programming data is latched.

Table 1. bq2054 Display Output Summary

<table>
<thead>
<tr>
<th>Mode</th>
<th>Charge Action State</th>
<th>LED1</th>
<th>LED2</th>
<th>LED3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSEL = 0</td>
<td>Battery absent or over-voltage fault</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>(Mode 1)</td>
<td>Pre-charge qualification</td>
<td>Flash</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Fast charging</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge complete</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge pending (temperature out of range)</td>
<td>X</td>
<td>X</td>
<td>Flash</td>
</tr>
<tr>
<td></td>
<td>Charging full</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>DSEL = 1</td>
<td>Battery absent or over-voltage fault</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>(Mode 2)</td>
<td>Pre-charge qualification</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Fast charging</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge complete</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge pending (temperature out of range)</td>
<td>X</td>
<td>X</td>
<td>Flash</td>
</tr>
<tr>
<td></td>
<td>Charging full</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>DSEL = Float</td>
<td>Battery absent or over-voltage fault</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>(Mode 3)</td>
<td>Pre-charge qualification</td>
<td>Flash</td>
<td>Flash</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Fast charge current regulation</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Fast charge voltage regulation</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge complete</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Charge pending (temperature out of range)</td>
<td>X</td>
<td>X</td>
<td>Flash</td>
</tr>
<tr>
<td></td>
<td>Charging full</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
</tbody>
</table>

Note: 1 = Vect; 9 = Vect X = LED state when fault occurred; Flash = X sec low, X sec high.
Fast charge termination when the charging current drops below a minimum current threshold programmed by the value of ITERM (see Table 2) and remains below that level for 120 ± 60ms.

Table 2. ITERM Termination Thresholds

<table>
<thead>
<tr>
<th>ITERM</th>
<th>kMIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>hRAT/10</td>
</tr>
<tr>
<td>1</td>
<td>hRAT/20</td>
</tr>
<tr>
<td>Float</td>
<td>hRAT/50</td>
</tr>
</tbody>
</table>

These parameters are typically specified by the battery manufacturer. The total resistance presented across the battery pack by R1 + R2 should be between 15Ω and 18Ω. The minimum value ensures that the divider network does not draw the battery excessively when the power source is disconnected. Raising the minimum value increases the noise susceptibility of the RAT pin.

The current sense resistor, RSEN (see Figure 5), determines the fast charge current. The value of RSEN is given by the following:

\[ I_{\text{RAT}} = \frac{0.220V}{R_{\text{SEN}}} \]

where:
- \( I_{\text{RAT}} \) = Desired maximum charge current

Voltage and Current Monitoring

The bq2054 monitors battery pack voltage at the RAT pin. The user must implement a voltage divider between the positive and negative terminals of the battery pack to present a scaled battery pack voltage to the RAT pin. The bq2054 also uses the voltage across a sense resistor (RSEN) between the negative terminal of the battery pack and ground to monitor the current into the pack. See Figure 4 for the configuration of this network.

The resistor values are calculated from the following equation:

\[ \frac{R1}{R2} = \frac{N \times V_{\text{SEN}}}{200V} - 1 \]

where:
- N = Number of cells in series
- \( V_{\text{SEN}} \) = Desired fast-charge voltage per cell

Figure 3 shows the bq2054 configured for display mode 2 and \( R_{\text{SEN}} = hRAT/10 \).

Hold-Off Period

Both VPRE and low terminations are ignored during the first 1.33 ± 0.19 seconds of both the Charge Qualification and Fast Charge phases. This condition prevents premature termination due to voltage spikes that may occur when charge is first applied.
Figure 2. Configured Display Mode/MIN Threshold

Figure 4. Configuring the Battery Divider
Battery Insertion and Removal

$V_{CELL}$ is interpreted by the bq2054 to detect the presence or absence of a battery. The bq2054 determines that a battery is present when $V_{CELL}$ is between the High-Voltage Cutoff ($V_{HCC} = V_{HCC}$ = 0.27 V) and the Low-Voltage Cutoff ($V_{LCC} = 0.8 V$). When $V_{CELL}$ is outside this range, the bq2054 determines that no battery is present and transmits to the Fault state. Transitions into and out of the range between $V_{HCC}$ and $V_{LCC}$ are treated as battery insertions and removals, respectively. The $V_{LCC}$ limit also implicitly serves as an overvoltage charge termination.

Inrush Current Control

Whenever the bq2054 is in the fault or charge-complete state, the CC2L output is driven low. This output may be used to disconnect the capacitor usually present in the charger across the positive and negative battery terminals, preventing the cap from supplying large inrush currents to a newly inserted battery. Such inrush currents may trip the overcurrent protection typically usually present in Li-Ion battery packs.

Temperature Monitoring

The bq2054 monitors temperature by examining the voltage presented between the TS and SNS pins by a resistor network that includes a Negative Temperature Coefficient (NTC) thermistor. Resistance variations around that value are interpreted, as being proportional to the battery temperature (see Figure 6).

The temperature thresholds used by the bq2054 and their corresponding T (°C) pin voltage are:

- TCO (Temperature Cutoff): Highest limit of the temperature range in which charging is allowed. $V_{TCO} = 0.4 \times V_{CC}$
- HTF (High-Temperature Fault): Threshold to which temperature must drop after temperature cutoff is exceeded before charging can begin again. $V_{HTF} = 0.44 \times V_{CC}$
- LTF (Low-Temperature Fault): Lower limit of the temperature range in which charging is allowed. $V_{LTF} = 0.6 \times V_{CC}$

![Figure 5. Configuring Temperature Sensing](image1)

![Figure 6. Voltage Equivalent of Temperature](image2)
A resistor-divider network can be implemented that presenting the defined voltage levels to the VS pin at the desired temperatures (see Figure 6).

The equations for determining RT1 and RT2 are:

Equation 3

\[ V_{in} = \frac{(V_{CC} \times 0.250)}{1 + \frac{RT1 + RT2 + R_{in}}{RT2 \times R_{in}})} \]

Equation 4

\[ 0.44 = \frac{1}{1 + \frac{RT1 + RT2 + R_{in}}{RT2 \times R_{in}}} \]

where:

- RT = thermistor resistance at T
- RT = thermistor resistance at T2

TOD is determined by the values of RT1 and RT2. 1% resistors are recommended.

Disabling Temperature Sensing

Temperature sensing can be disabled by placing 10kΩ resistors between VS and SNS and between SNS and VCC.

Maximum Time-Out

MTO is programmed from 1 to 24 hours by an R-C network on the TM pin (see Figure 7) per the equation:

Equation 5

\[ MTO = 0.5 \times R \times C \]

Where R is in kΩ and C is in μF. tMTO is in hours. The maximum value for C (0.1 μF) is typically used.

The MTO timer is reset at the beginning of fast charge and when fast charge transitions from the current regulated to the voltage regulated mode. If MTO expires during the current regulated phase, the bq2054 enters the Fault state and terminates charge. If the MTO timer expires during the voltage regulated phase, fast charging terminates and the bq2054 enters the Charge Complete state.

The MTO timer is suspended (but not reset) during the out-of-range temperature (Charge Pending) state.

Charge Regulation

The bq2054 controls charging through pulse-width modulation of the MOD output pin, supporting both constant-current and constant-voltage regulation. Charge current is monitored at the SNS pin, and charge voltage is monitored at the BAT pin. These voltages are compared to an internal reference, and the MOD output is modulated to maintain the desired value.

Voltage at the SNS pin is determined by the value of resistor RSEN, so nominal regulated current is set by:

Equation 6

\[ I_{MAX} = 0.250 \times \text{RSEN} \]

The switching frequency of the MOD output is determined by an external capacitor (CIFWM) between the pin TIFWM and ground, per the following:

Equation 7

\[ f_{PWM} = \frac{1}{2 \pi} \sqrt{\frac{C_{IFWM}}{P}} \]

Where C is in μF and P is in kHz. A typical switching rate is 100kHz, implying C_{IFWM} = 0.0125μF. MOD pulse width is modulated between 0 and 50% of the switching period.

To prevent oscillation in the voltage and current control loops, frequency compensation networks (C2 or C1) are typically required on the VCCAP and IREF pin(s) respectively.

Figure 7. R-C Network for Setting MTO
### Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Unit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vcc</td>
<td>Vcc relative to Vss</td>
<td>-0.3 V</td>
<td>+7.0 V</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Vt</td>
<td>DC voltage applied on any pin excluding Vcc relative to Vss</td>
<td>-0.3 V</td>
<td>+7.0 V</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>TTEMP</td>
<td>Operating ambient temperature</td>
<td>-20 °C</td>
<td>+70 °C</td>
<td>°C</td>
<td>Commercial</td>
</tr>
<tr>
<td>TSTG</td>
<td>Storage temperature</td>
<td>-55 °C</td>
<td>+125 °C</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>TSDIR</td>
<td>Soldering temperature</td>
<td>-</td>
<td>+260 °C</td>
<td>°C</td>
<td>30 sec. max.</td>
</tr>
</tbody>
</table>

**Note:** Permanent device damage may occur if **Absolute Maximum Ratings** are exceeded. Functional operation should be limited to the **Recommended DC Operating Conditions** detailed in this data sheet. Exposure to conditions beyond the operational limits for extended periods of time may affect device reliability.
## DC Thresholds  (TA = 105°C; VCC = 5V ±10%)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Rating</th>
<th>Unit</th>
<th>Tolerance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VREF</td>
<td>Internal reference voltage</td>
<td>2.05V</td>
<td>V</td>
<td>±1%</td>
<td>T_A = 25°C</td>
</tr>
<tr>
<td></td>
<td>Temperature coefficient</td>
<td>-0.5 mV/°C</td>
<td>V</td>
<td>±10%</td>
<td></td>
</tr>
<tr>
<td>VTTY</td>
<td>TS maximum threshold</td>
<td>0.6 × VCC</td>
<td>V</td>
<td>±0.05V</td>
<td>Low-temperature fault</td>
</tr>
<tr>
<td>VTHY</td>
<td>TS hysteresis threshold</td>
<td>0.44 × VCC</td>
<td>V</td>
<td>±0.05V</td>
<td></td>
</tr>
<tr>
<td>VTCO</td>
<td>TS minimum threshold</td>
<td>0.4 × VCC</td>
<td>V</td>
<td>±0.05V</td>
<td>Temperature cutoff</td>
</tr>
<tr>
<td>VTHO</td>
<td>High cutoff voltage</td>
<td>2.3V</td>
<td>V</td>
<td>±1%</td>
<td></td>
</tr>
<tr>
<td>VAEN</td>
<td>Under-voltage threshold at EAT</td>
<td>0.2 × VCC</td>
<td>V</td>
<td>±0.05V</td>
<td></td>
</tr>
<tr>
<td>VLOO</td>
<td>Low cutoff voltage</td>
<td>0.8</td>
<td>V</td>
<td>±0.05V</td>
<td></td>
</tr>
<tr>
<td>VNSN</td>
<td>Current sense at SNS</td>
<td>0.250 V</td>
<td>V</td>
<td>±10%</td>
<td>I_{max}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.050 V</td>
<td>V</td>
<td>±10%</td>
<td>I_{max}</td>
</tr>
</tbody>
</table>


## Recommended DC Operating Conditions (TA = T0(RR))

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCC</td>
<td>Supply voltage</td>
<td>4.5</td>
<td>5.0</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VRMR</td>
<td>Temperature sense voltage</td>
<td>0</td>
<td>-</td>
<td>VCC</td>
<td>V</td>
<td>VCC - VSS</td>
</tr>
<tr>
<td>VRMM</td>
<td>Port cell battery voltage input</td>
<td>0</td>
<td>-</td>
<td>VCC</td>
<td>V</td>
<td>VDD2 - VSS</td>
</tr>
<tr>
<td>ICC</td>
<td>Supply current</td>
<td>-</td>
<td>2</td>
<td>4</td>
<td>mA</td>
<td>Output unloaded</td>
</tr>
<tr>
<td>ISOL</td>
<td>ISO low-state open detection</td>
<td>-2</td>
<td>-</td>
<td>2</td>
<td>mA</td>
<td>Note 2</td>
</tr>
<tr>
<td>IOL</td>
<td>ISO tri-state open detection</td>
<td>-2</td>
<td>-</td>
<td>2</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>VIL</td>
<td>Logic input high</td>
<td>VCC-0.3</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>ISEL, ITRI</td>
</tr>
<tr>
<td>VIL</td>
<td>Logic input low</td>
<td>-</td>
<td>-</td>
<td>VCC+0.3</td>
<td>V</td>
<td>BSEL, Invert</td>
</tr>
<tr>
<td>VIL</td>
<td>LED, I/O, output high</td>
<td>VCC-0.8</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>Log &lt; 10mA</td>
</tr>
<tr>
<td>VIL</td>
<td>MOD output high</td>
<td>VCC-0.8</td>
<td>-</td>
<td>-</td>
<td>V</td>
<td>Log &lt; 10mA</td>
</tr>
<tr>
<td>VIL</td>
<td>LED, I/O, output low</td>
<td>-</td>
<td>-</td>
<td>VCC+0.8</td>
<td>V</td>
<td>Log &lt; 10mA</td>
</tr>
<tr>
<td>VIL</td>
<td>MOD output low</td>
<td>-</td>
<td>-</td>
<td>VCC+0.5</td>
<td>V</td>
<td>Log &lt; 50mA</td>
</tr>
<tr>
<td>VIL</td>
<td>LED, I/O, source</td>
<td>-10</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>VCC = VCC+0.3V</td>
</tr>
<tr>
<td>VIL</td>
<td>MOD source</td>
<td>-5.0</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>VCC = VCC-0.5V</td>
</tr>
<tr>
<td>VIL</td>
<td>LED, I/O, sink</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>VCC = VCC-0.5V</td>
</tr>
<tr>
<td>VIL</td>
<td>MOD sink</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>VCC = VCC-0.5V</td>
</tr>
<tr>
<td>VIL</td>
<td>LCOM sink</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>VCC = VCC-0.5V</td>
</tr>
<tr>
<td>VIL</td>
<td>BSEL logic input low source</td>
<td>-</td>
<td>-</td>
<td>VSS+0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VIL</td>
<td>BSEL logic input low source</td>
<td>-</td>
<td>-</td>
<td>VSS+0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VIL</td>
<td>BSEL logic input high source</td>
<td>-50</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td>Y = VCC + 0.5V to VSS</td>
</tr>
<tr>
<td>VIL</td>
<td>BSEL logic input high source</td>
<td>-70</td>
<td>-</td>
<td>-</td>
<td>mA</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

1. All voltages relative to VSS except where noted.
2. Conditions during initialization after VCC applied.
### Impedance

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Minimum</th>
<th>Unit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVE2</td>
<td>BAT pin input impedance</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>MΩ</td>
<td></td>
</tr>
<tr>
<td>RAV2</td>
<td>SS pin input impedance</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>MΩ</td>
<td></td>
</tr>
<tr>
<td>RAV1</td>
<td>TS pin input impedance</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>MΩ</td>
<td></td>
</tr>
<tr>
<td>RTHDH1</td>
<td>Soft-programmed pull-up or pull-down resistor values (for programming)</td>
<td>-</td>
<td>-</td>
<td>10 kΩ</td>
<td></td>
<td>DESL</td>
</tr>
<tr>
<td>RTHDG2</td>
<td>Pull-up or pull-down resistor value</td>
<td>-</td>
<td>-</td>
<td>5 kΩ</td>
<td></td>
<td>Jumps</td>
</tr>
<tr>
<td>RHTO2</td>
<td>Charge timer resistor</td>
<td>30</td>
<td>-</td>
<td>4.85</td>
<td>kΩ</td>
<td></td>
</tr>
</tbody>
</table>

### Timing (TA = TOPR; VCC = 3V ± 10%)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Minimum</th>
<th>Unit</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTCO</td>
<td>Charge timer-out range</td>
<td>1</td>
<td>-</td>
<td>24</td>
<td>hour</td>
<td>See Figure 7</td>
</tr>
<tr>
<td>tQR</td>
<td>Pre-charge qual test time-out period</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>tGD</td>
<td>Termination hold-off period</td>
<td>1.4</td>
<td>-</td>
<td>1.52</td>
<td>sec</td>
<td></td>
</tr>
<tr>
<td>tACC</td>
<td>Min. current detect filter period</td>
<td>80</td>
<td>-</td>
<td>160</td>
<td>msec</td>
<td></td>
</tr>
<tr>
<td>FPWM</td>
<td>PWM regulator frequency range</td>
<td>-</td>
<td>100</td>
<td></td>
<td>kHz</td>
<td></td>
</tr>
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</table>

### Capacitance

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHTO</td>
<td>Charge timer capacitor</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>μF</td>
</tr>
<tr>
<td>CRM</td>
<td>PWM E-C capacitance</td>
<td>-</td>
<td>0.601</td>
<td>-</td>
<td>μF</td>
</tr>
</tbody>
</table>
Data Sheet Revision History

<table>
<thead>
<tr>
<th>Change No.</th>
<th>Page No.</th>
<th>Description</th>
<th>Nature of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5, 7, 8, 10</td>
<td>Value Change</td>
<td>Changed $V_{DD}$ and $I_{MAX}$</td>
</tr>
<tr>
<td>2</td>
<td>5, 10</td>
<td>Value Change</td>
<td>Changed $V_{REF}$</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>Coefficient Addition</td>
<td>Temperature coefficient added</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>New state diagram</td>
<td>Diagram inserted</td>
</tr>
<tr>
<td>4</td>
<td>1, 2, 8, 12</td>
<td>NC pin replaced with TTL</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3, 5, 13</td>
<td>Termination hold-off period added</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>$V_{OH}$ testing changed to 2.3V</td>
<td>Changed values for $V_{OH}$</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>$t_{QP}$ in Timing Specifications</td>
<td>$t_{QP}$ changed from (9.16 + $t_{MTU}$) to $t_{MTU}$</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>Fromm in Table 2</td>
<td>$Z$ changes to float</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>Figure 6</td>
<td>$R_{F1}$ and $R_{F2}$ changed to $R_{TF}$ and $R_{TF}$</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>Top</td>
<td>Deleted industrial temperature range</td>
</tr>
</tbody>
</table>

Notes:
- Change 3 = April 1996 C changes from Dec. 1995 B.
- Change 4 = Sept. 1996 D changes from April 1996 C.
- Change 5 = Nov. 1996 E changes from Sept. 1996 D.
- Change 6 = Oct. 1997 F changes from Nov. 1996 E.
- Change 8 = June 1999 H changes from Oct. 1997 G.

Ordering Information

- **bq2054**
- **Package Option:**
  - FN = 16 pin plastic DIP
  - SN = 16 pin narrow SOIC
- **Device:**
  - bq2054 Li-Ion Fast-Charge IC

---

B-56
## Packaging Information

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status (1)</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Exo Plan (2)</th>
<th>LeadBall Finish</th>
<th>MSL Peak Temp (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ2044P4N</td>
<td>ACTIVE</td>
<td>PDP</td>
<td>N</td>
<td>10</td>
<td>20</td>
<td>Pb-Free (RoHS)</td>
<td>Cu NiPdAu</td>
<td>N/A for Plg Type</td>
</tr>
<tr>
<td>BQ2044P4NE4</td>
<td>ACTIVE</td>
<td>PDP</td>
<td>N</td>
<td>18</td>
<td>38</td>
<td>Pb-Free (RoHS)</td>
<td>Cu NiPdAu</td>
<td>N/A for Plg Type</td>
</tr>
<tr>
<td>BQ2045SN4E6</td>
<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>18</td>
<td>40</td>
<td>Green (RoHS &amp; no SnBr)</td>
<td>Cu NiPdAu</td>
<td>Level-1-2020C-UNLIM</td>
</tr>
<tr>
<td>BQ2044SNG4</td>
<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>18</td>
<td>40</td>
<td>Green (RoHS &amp; no SnBr)</td>
<td>Cu NiPdAu</td>
<td>Level-1-2020C-UNLIM</td>
</tr>
<tr>
<td>BQ2045SNTR</td>
<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>18</td>
<td>2500</td>
<td>Green (RoHS &amp; no SnBr)</td>
<td>Cu NiPdAu</td>
<td>Level-1-2020C-UNLIM</td>
</tr>
<tr>
<td>BQ2045SNTR4</td>
<td>ACTIVE</td>
<td>SOIC</td>
<td>D</td>
<td>18</td>
<td>2500</td>
<td>Green (RoHS &amp; no SnBr)</td>
<td>Cu NiPdAu</td>
<td>Level-1-2020C-UNLIM</td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
- ACTIVE: Product device recommended for new designs.
- LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- N/RND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
- OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or (Green) (RoHS & no SnBr) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
- TBD: The Pb-Free (Green conversion) plan has not been defined.
- Pb-Free (RoHS): TI terms “Lead-Free” or “Pb-Free” or “Pb-Free (RoHS)” to mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
- Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-free flip-chip solder bumps used between the die and package, or 2) lead-free die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
- Green (RoHS & no SnBr): TI defines “Green” to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material).

(3) MSL Peak Temp - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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100VAC Input/5VDC (100mA) Output

Non-Isolated AC/DC Converter

BP5034D5

- Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Limits</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>V</td>
<td>195</td>
<td>V</td>
</tr>
<tr>
<td>Output current</td>
<td>Ic</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>ESD endurance</td>
<td>Vage</td>
<td>2</td>
<td>KV</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>Top</td>
<td>-20 to 85</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>Ts</td>
<td>-25 to 85</td>
<td>°C</td>
</tr>
</tbody>
</table>

- Electrical Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage range</td>
<td>Vt</td>
<td>113</td>
<td>141</td>
<td>156</td>
<td>V</td>
<td>DC(80 to 125VAC)</td>
</tr>
<tr>
<td>Output voltage</td>
<td>Vo</td>
<td>4.7</td>
<td>5.0</td>
<td>5.9</td>
<td>V</td>
<td>V&lt;14V, I&lt;50mA</td>
</tr>
<tr>
<td>Output current</td>
<td>I10</td>
<td>0</td>
<td>100</td>
<td>1mA</td>
<td>nA</td>
<td>V&lt;14V</td>
</tr>
<tr>
<td>Line regulation</td>
<td>VF</td>
<td>-0.02</td>
<td>0.1</td>
<td>V</td>
<td>V</td>
<td>V&lt;113 to 196V, I&lt;80mA</td>
</tr>
<tr>
<td>Load regulation</td>
<td>VF</td>
<td>0.05</td>
<td>0.15</td>
<td>V</td>
<td>V</td>
<td>V&lt;10V</td>
</tr>
<tr>
<td>Output ripple voltage</td>
<td>Vp</td>
<td>0.05</td>
<td>0.15</td>
<td>V</td>
<td>V</td>
<td>V&lt;14V</td>
</tr>
<tr>
<td>Power conversion efficiency</td>
<td>η</td>
<td>48</td>
<td>56</td>
<td>-</td>
<td>%</td>
<td>V&lt;14V, I&lt;100mA</td>
</tr>
</tbody>
</table>

*1 Minimum output current varies depending on ambient temperature; please refer to derating curve.
*2 Please refer to load regulation, conversion efficiency.

- Application Circuit

BP5034D5

- External Component Specifications

FUSE: Rated
C1: Input smoothing capacitor
Rated capacity: 2.2nF or higher
C2: Noise reduction capacitor
Rated capacity: 3.3 to 70μF
C3: Output smoothing capacitor
Rated capacity: 100μF or higher, low impedance
Impedance: 0.01Ω (max) high frequencies
R1: Rectifier diode
Ripple current: 200mA or higher, and the forward surge current should be 50mA or higher.
R1: Noise reduction resistor
Ripple current: 200mA or higher
ZNR: Varistor
A varistor must be used to protect against lightning surge and static electricity.
Power Module Usage Precautions

/Safety Precautions/

1) The products are designed and manufactured for use in ordinary electronic equipment (i.e., AV/OA/telecommunication/amusement equipment, home appliances). Please consult with the Company’s (ROHM) sales staff if intended for use in devices requiring high reliability (e.g., medical/transport/aircraft/spacecraft equipment, nuclear power/fuel controllers, automotive/safety devices) and whose malfunction may result in injury or death. In this case, fail-safe measures must be taken, including the following:
[a] Installation of protection circuits in order to improve system safety
[b] Incorporation of redundant circuits in the case of single-circuit failure

2) The products are designed for use under normal conditions. Application in special environments can cause a deterioration in product performance. Therefore, verification and confirmation of product performance, prior to use, is recommended. The following environments are considered to be 'special':
[a] Outdoors, exposed to direct sunlight or dust
[b] In contact with liquids such as water, oils, chemicals, or organic solvents
[c] In areas where exposure to the sea air or corrosive gases (e.g., Cl₂, H₂S, NH₃, SO₂, NO₂) can occur
[d] In places where the products may be in contact with static electricity or electromagnetic waves
[e] In proximity to heat-producing items, plastic cords, or flammable materials
[f] In contact with sealing or coating products, such as resin
[g] In contact with unsuitable solder or exposed to water or water-soluble cleaning agents used after soldering
[h] In areas where dew condensation occurs

3) The products are not designed to be radiation resistant
4) The Company is not responsible for any problems resulting from use of the products under conditions not recommended herein.
5) The Company should be notified of any product safety issues. Moreover, product safety issues should be periodically monitored by the customer.

/Application Notes/

1) A sufficient margin must be allowed if changes are made to the peripheral circuit due to variations in the inherent tolerances of the external components as well as transient and static characteristics. In addition, please be aware that the Company has not conducted investigations on whether or not particular changes in the example application circuits would result in patent infringement.

2) The application examples, their constants, and other types of information contained herein are applicable only when the products are used in accordance with standard methods. Therefore, if mass production is intended, sufficient consideration to external conditions must be made.

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[a] Infringement of the intellectual property rights of a third party
[b] Problems arising from the use of the products listed herein

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