OVERCURRENT PROTECTION REFERENCE DESIGN & STUDY

Sponsor: Texas Instruments

Project Contact: Pete Semig

Michigan State University
ECE 480: Senior Design
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Design Team 5:
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Executive Summary

This project's purpose is to design, test, and document multiple real-world over-current protection application circuits. Designs will focus on placing Texas Instrument components on a printed circuit board to demonstrate the application of theory. The project is a complete engineering design cycle, from receiving specifications to final documentation of findings, and qualifies for participation in Texas Instrument's Analog Design Competition.

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Introduction

Current flow in an electrical device will always generate heat, and the greater the current flow, the hotter the component becomes. Excess heat can damage electrical components, for this reason, most components have a rated maximum current carrying capacity. Overcurrent protection (OCP) devices are used to protect circuits from current flow exceeding this rating. These protective devices are designed to keep the flow of current in a circuit at a safe level to prevent any components from overheating in case of a malfunction inside the circuit.

OCP has been implemented in many mechanical forms, such as through circuit breakers, ground fault circuit interrupters, and fuses. Due to recent improvements in technology and decreases in the cost of such technology, OCP can now be designed using integrated circuit systems for minimal cost, with less wear compared to mechanical systems. Electrical OCP systems are usually made with a variety of shunt monitors, op-amps, and microcontrollers.

Texas Instruments (TI) is a company that specializes in various electrical systems, and is in need of a reference design for electrical OCP systems. TI has requested two different applications to design and implement OCP systems for: a tablet-pc, as well as a consumer cellphone. For the tablet-pc application, as soon as any excess current draw is detected, power to the system is cut and the system is shutdown, this is done by monitoring the supply current. In the cellphone application, the load current of the cellphone will be accurately monitored, and decisions made only on certain current draw. For both designs, select TI components from a large portfolio will be utilized, including the MSP430 microcontroller and several models of current shunt monitors.

Design Specifications

The following specifications were given by TI Analog Application Engineer Pete Semig:

Design a Tablet-PC OCP system that shuts down the supply current if excess current is drawn.

- Assume battery is Li-polymer with 3.6 V, 6.75 A-hr.
- Use 1A for the trip current.
- Design a test fixture that emulates three different scenarios:
    - Normal Load (750 mA, should not cause shutdown)
    - High Current Load (draws current greater than 1A, trips shutdown)
    - Variable Load that trips at a random time (Example: A Thermistor will trip if it exceeds a certain temperature.)
- The priorities for this application are as follows:
    - Low Power
    - Small Size
    - Low Cost
    - Speed of Shutoff
    - Accuracy

Design a Cellphone OCP system that monitors load current of a cellphone.

- Accurate power consumption monitoring is critical
- Required precision between 7-192.5 mA
- Assume supply voltage is 3.0 V regulated
- Load requires 2.7-3.3V
- The priorities for this application are as follows:
    - Minimal System Impact
    - Accuracy
    - Small Size

The following deliverables are also required:

- Block Diagrams
- Component Selection and Justification
- Design Studies and testing
- Circuit Diagrams and PCB layouts
- Results and Demonstrations

Current Sensing Background Information

Several current sensing methods are in existence today: R_{ds} MOSFET sensing, Hall-effect, current transformers, resistive shunts, and more exotic methods. Choosing an appropriate method for the given design requirements requires some knowledge on how each procedure may affect system performance.

R_{ds} MOSFET sensing uses the characteristic impedance between the drain and source of the MOSFET (if used as a switch) in a power supply and the voltage at the switch to infer the current flowing through the circuit. This method is not useful in solving the giving design requirements because it requires a MOSFET switch, which would not exist when running the current sensing application using a battery. [1]

Hall-effect current sensing is a common solution, which does not suffer from insertion losses that reduce useful battery life. The main concept is to focus a flux field using a toroid such that current flow through a conductor placed within the toroid induces a magnetic field. By observing the generated magnetic flux density, one may figure the amount of current flow. However, this method is undesirable because of the increased PCB real estate usage and increased cost for the components required by this process. [2]

Current transformers, like Hall-effect current sensing, allow for circuit isolation and zero insertion losses. This method also has zero offset voltage and requires no external power. The concept is basic transformer theory, running current through an inductor (winding) allows for coupling to another inductor, with current proportional to the number of turns in each winding. Also like the Hall-effect method, current transformers are expensive and require large amounts of PCB real estate, but perhaps most debilitating is that this method requires AC current and the design specifications call for current sensing on batteries, which are inherently DC. [2]

Resistive shunts require placing a resistance in series with the power source and the load, and measuring the voltage drop across said resistance to calculate the current flowing through the circuit. This method is low cost, although it suffers from insertion loss and may require signal amplification of the measured voltage. Two distinct uses of the resistive shunt exist; low side current sensing and high side current sensing. Low side current sensing places the resistive shunt between the load and the ground, which allows for easy implementation of current sensing using nothing but an operational amplifier. However, it also adds impedance to the load's line to ground, which may affect system performance. High side current sensing, on the other hand, places its resistive shunt between the power source and the load, which does not add a disturbance to ground. Both methods can be designed for fast, precise, and accurate operation, factors important to meeting the design requirements. Due to low cost, low PCB real estate requirements, and performance capabilities, it is likely that this method will satisfy the design requirements. [3]

Methods that are more exotic are currently beyond consideration, as resistive shunts appear to satisfy design needs, however if resistive shunts do not perform as expected these options will be explored.

Use Of A Microprocessor And Programming

Until the development of more concrete circuit designs to satisfy the design requirements are complete, it is difficult to state how useful a microprocessor may be in the current sensing application. Potential uses for a microprocessor may include; notifying the user that a problem has occurred while shutting down the affected system, providing increased accuracy in current sensing capabilities, and satisfying requirements for the TI Analog Design Competition. Although the use of a microcontroller in the current sensing application has not been decided upon, a microcontroller is necessary for the test bench. The test bench will supply several possible current levels for use in testing prototyped circuit designs, and it is desirable to have an LCD output showing current levels as well as digital control of current levels for automatic testing. Upon a query of TI microprocessors that have the capability to fulfill these requirements, the MSP430 with a built-in LCD driver is highly attractive. Software development for this microcontroller may be done in Code Composer Studio, which allows a programmer to use the C/C++ language.

Design Concepts[5]

Application One:

This application is to build a design to protect a tablet PC from a receiving more than 1A of current by cutting the load from its power supply using a TI current shunt monitor to monitor the input current. This can be achieved using, exclusively, analog components from Texas Instruments. A current shunt monitor can measure the input current by measuring the voltage drop across a current shunt resistor. The current shunt monitor will then give an output determined by an equation with the only variable being the input current. For example, the TI INA138 Current Shunt Monitor gives the output: $V_0 = \frac{R_s R_L I_s}{R_{CSM}}$, where

R_s = Current Shunt Resistor, R_L = Output Resistor of Current Shunt Monitor,

I_s = Input Current, R_{CSM} = Known Resistance Value Within the Current Shunt Monitor, and

V_o = Output of the Current Shunt Monitor.

This known output can now be connected to the input of an analog comparator, with the other input coming from a feedback of the analog comparator output in parallel to the power source that allows a reference current of 1A to be created. If the output of the Current Shunt Monitor is greater than the 1A output, the comparator will output low. This output is then hooked into a switch; some possibilities include a TI Load Switch or a MOSFET. If the input into the switch is low, the switch will turn off, cutting the power to the load and protecting it from too much current. The advantage of using a load switch is that it allows controllable slew rate (switching speed) and are available at low cost. However, since the solder connections are on the bottom of the part, testing the component on a printed circuit board is significantly more difficult than using a MOSFET.

Some possible parts for this application include: the TI INA138 current shunt monitor, the TI TLV3491 CMOS rail-to-rail push-pull output comparator, and the TI TPS22907 load switch. A working stage block diagram and accompanying schematic are shown below.

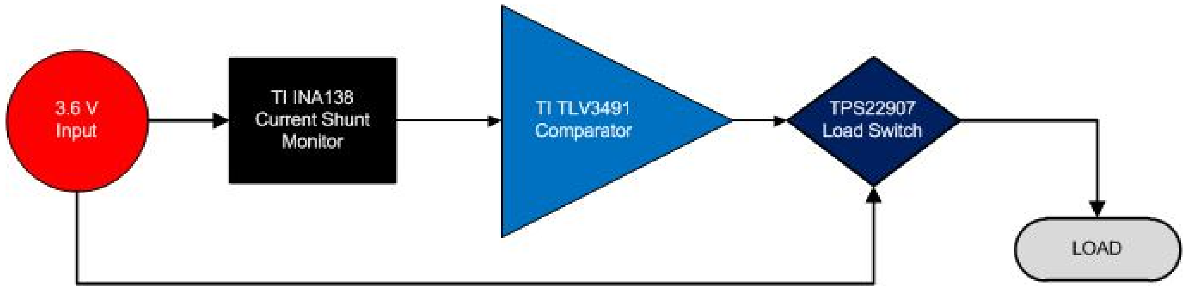

Figure 1: Block Diagram for Application One OCP

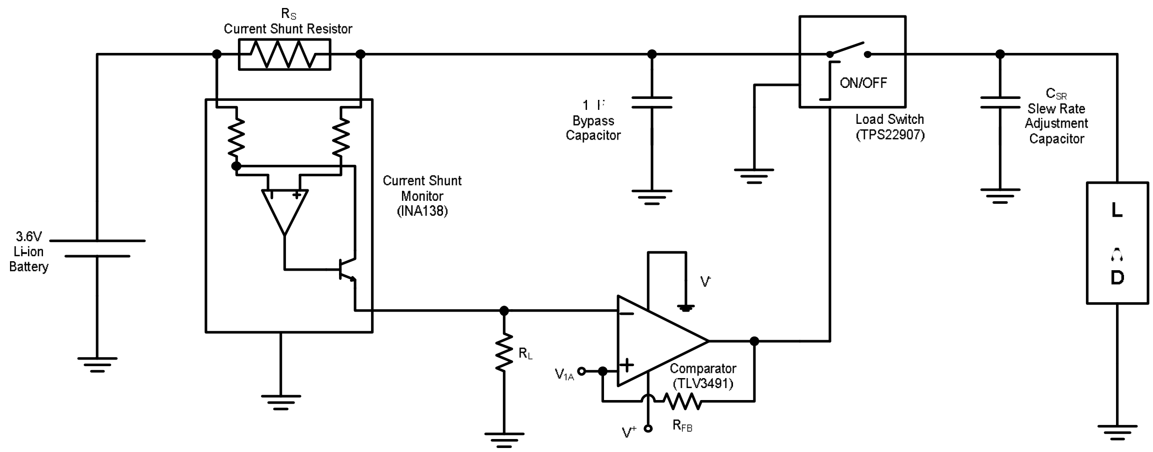

Figure 2: Schematic for Application One OCP

Application Two

This application will monitor the current being input into a cellphone to correctly determine the power being consumed for different applications. To achieve this, using a current shunt monitor is also useful in measuring the current draw from the power supply. The output of the current shunt monitor will be input into a TI MSP430 microcontroller to process the information. This processor allows for: analog to digital conversion, digital processing of information, and LCD display output of the current levels. For this application, additional studies were requested. These include changing the position of the shunt resistor, experimenting with Kelvin connections, and variations in PCB trace width and length.

The software cannot be design until the MSP430's functionality is well understood.

Team Management

Schedule / Plan

As explained in previous sections, this project includes the design and testing of two over-current protection applications. To begin with, preliminary design ideas must be simulated, prototyped, and tested. Alterations may be made to components and other design factors, based on the results of testing. Texas Instruments has also requested that studies be completed to document which design procedures have the most desirable outcomes. These findings will aid in the designing of a final prototype. Fabrication on a printed circuit board is a requirement of the final prototype design. At this stage, there must be ample time left before Design Day for any adjustments or revisions.

Team Members

This is a brief introduction of the members of ECE 480 Design Team Five and their technical and non-technical roles. The roles shown below are considered as the minimum expected from that team member. It is expected that all team members will participate in the completion of all aspects of the project, whether it be technical or non-technical.

Team Member	Non-Technical Role
Stephen England	Team Management
Joshua Myers	Webmaster
Kenji Aono	Document Preparation
Ryan Laderach	Presentation Preparation/Lab Coordinator

Team Member	Technical Role
Stephen England	Hardware Design Application 1/Simulation and Testing
Joshua Myers	Hardware Design Application 1/PCB Design and Testing
Kenji Aono	Hardware Design Application 2/Software Lead
Ryan Laderach	Hardware Design Application 2/Software Support

Budget [4]

Item	Cost
Current Shunt Monitor	$5.26
MSP430 412 microprocessor	$8.68
PCB Fabrication	$150.00
TI Comparators	$4.52
Current Shunt Resistors	$6.26
Switches	$0.88
MSP430 Target Board	$75.00
MSP430 Target Board with USB	$149.00
Total cost without USB	**$250.60**
Total cost with USB	**$324.60**

Cost Justification

Current Shunt Monitor: The current shunt monitor is required to actively monitor if the load is drawing over 1 A of current.

Current Shunt Resistors: The resistors need to have a uncommonly low resistance to allow the maximum power transfer between the supply and load.

MSP430 412: This microcontroller has a built in LCD drivers capable of displaying the current being drawn, as well as satisfying compute requirements while maintaining a low power profile.

PCB fabrication: The sponsor has requested that several PCBs are used in our applications; the ECE shop may not fulfill certain design requirements.

MSP430 Target Board: The development boards will allow for rapid deployment of code and improve debugging capabilities.

References

[1] Gabriel A. Rincón-Mora and H. Pooya Forghani-zadeh, "Accurate and Lossless Current-Sensing Techniques: A Practical Myth?" Power Management Design Line, Mar. 17, 2005.

[2] Paul Emerald, "Non-Intrusive Hall-Effect Current-Sensing Techniques Provide Safe, Reliable Detection and Protection for Power Electronics," in International Appliance Technical Conference, Ohio State University, May 6, 1998, pp 1-2.

[3] Texas Instruments, "What is a Current Sensor and How is it Used?", Last Accessed on Feb. 10, 2011. Available at: http://focus.ti.com/analog/docs/microsite.tsp?familyId=57&micrositeId=7&sectionId=560&tabId=2180

[4] Digikey Catalogue, Last Accessed on Feb 10, 2011. Available at http://www.digikey.com/

[5] TI Website (Part Datasheets), Last Accessed on Feb 10, 2011. Available at http://www.ti.com/