

Micrel's Guide to

Designing With Low-Dropout Voltage Regulators

Bob Wolbert

Applications Engineering Manager

Revised Edition, December 1998

Micrel Semiconductor

1849 Fortune Drive

San Jose, CA 95131

Phone: + 1 (408) 944-0800

Fax: + 1 (408) 944-0970

Micrel, The High Performance Analog Power IC Company

Micrel Semiconductor designs, develops, manufactures, and markets high performance analog power integrated circuits on a worldwide basis. These circuits are used in a wide variety of electronic products, including those in cellular communications, portable and desktop computers, and in industrial electronics.

Micrel History

Since its founding in 1978 as an independent test facility of integrated circuits, Micrel has maintained a reputation for excellence, quality and customer responsiveness that is second to none.

In 1981 Micrel acquired its first independent semiconductor processing facility. Initially focusing on custom and specialty fabrication for other IC manufacturers, Micrel eventually expanded to develop its own line of semicustom and standard product Intelligent Power integrated circuits. In 1993, with the continued success of these ventures, Micrel acquired a new 57,000 sq. ft. facility and in 1995 expanded the campus into a 120,000 sq. ft. facility. The new Class 10 facility has allowed Micrel to extend its process and foundry capabilities with a full complement of CMOS/DMOS/Bipolar/NMOS/PMOS processes. Incorporating metal gate, silicon gate, dual metal, dual poly and feature sizes down to 1.5 micron, Micrel is able to offer its customers unique design and fabrication tools.



Micrel Today and Beyond

Building on its strength as an innovator in process and test technology, Micrel has expanded and diversified its business by becoming a recognized leader in the high performance analog power control and management markets.

The company's initial public offering in December of 1994 and recent ISO9001 compliance are just two more steps in Micrel's long range strategy to become the preeminent supplier of high performance analog power management and control ICs. By staying close to the customer and the markets they serve, Micrel will continue to remain focused on cost effective standard product solutions for an ever changing world.

The niche Micrel has carved for itself involves:

- **High Performance**.....precision voltages, high technology (Super β PNP™ process, patented circuit techniques, etc.) combined with the new safety features of overcurrent, overvoltage, and overtemperature protection
- **Analog**.....we control continuously varying outputs of voltage or current as opposed to digital ones and zeros (although we often throw in "mixed signal" i.e. analog with digital controls to bring out the best of both worlds)
- **Power ICs**.....our products involve high voltage, high current, or both

We use this expertise to address the following growing market segments:

1. Power supplies
2. Battery powered computer, cellular phone, and handheld instruments
3. Industrial & display systems
4. Desktop computers
5. Aftermarket automotive
6. Avionics
7. Plus many others

Copyright © 1998 Micrel, Inc.

All rights reserved. No part of this publication may be reproduced or used in any form or by any means without written permission of Micrel, Incorporated.

Some products in this book are protected by one or more of the following patents: 4,914,546; 4,951,101; 4,979,001; 5,034,346; 5,045,966; 5,047,820; 5,254,486; and 5,355,008. Additional patents are pending.

Contents

Contributors: 7

Section 1. Introduction:

Low-Dropout Linear Regulators 8

 What is a Linear Regulator? 8

 Why Use Regulators? 8

 Basic Design Issues 9

 What is a “Low-Dropout” Linear Regulator? 10

 Linear Regulators vs. Switching Regulators 11

Who Prefers Linear Low Dropout Regulators? 11

Section 2. Low-Dropout Regulator

Design Charts 12

 Regulator Selection Charts 12

 Regulator Selection Table 14

 Maximum Power Dissipation by Package Type 16

 Typical Thermal Characteristics 17

 Output Current vs. Junction Temperature and Voltage Differential 18

 Junction Temperature Rise vs. Available Output Current
 and Differential Voltage 21

Section 3. Using LDO Linear Regulators 24

 General Layout and Construction Considerations 24

Layout 24

 Bypass Capacitors 24

 Output Capacitor 24

 Circuit Board Layout 25

Assembly 25

 Lead Bending 26

 Heat Sink Attachment 26

 Output Voltage Accuracy 27

Adjustable Regulator Accuracy Analysis 27

Improving Regulator Accuracy 28

Regulator & Reference Circuit Performance 29

 Design Issues and General Applications 31

Noise and Noise Reduction 31

Stability 31

LDO Efficiency 31

Building an Adjustable Regulator Allowing 0V Output 31

 Reference Generates a “Virtual VOUT” 31

 Op-Amp Drives Ground Reference 32

Systems With Negative Supplies 32

<i>High Input Voltages</i>	33
<i>Controlling Voltage Regulator Turn-On Surges</i>	33
The Simplest Approach	34
Improving the Simple Approach	34
Eliminating Initial Start-Up Pedestal	35
<i>Current Sources</i>	36
Simple Current Source	36
The Super LDO Current Source	36
Accurate Current Source Using Op Amps	36
<i>A Low-Cost 12V & 5V Power Supply</i>	36
Computer Power Supplies	38
<i>Dropout Requirements</i>	38
<i>5V to 3.xV Conversion Circuits</i>	39
Method 1: Use a Monolithic LDO	39
Method 2: The MIC5156 "Super LDO"	39
Method 3: The MIC5158 "Super LDO"	40
Method 4: Current Boost a MIC2951	40
<i>Adjust Resistor Values</i>	40
<i>3.3V to 2.xV Conversion</i>	41
<i>Improving Transient Response</i>	41
<i>Accuracy Requirements</i>	42
<i>Multiple Output Voltages</i>	43
<i>Multiple Supply Sequencing</i>	44
<i>Thermal Design</i>	44
Portable Devices	45
<i>Design Considerations</i>	45
Small Package Needed	45
Self Contained Power	45
Low Current (And Low Voltage)	45
Low Output Noise Requirement	45
Dropout and Battery Life	46
Ground Current and Battery Life	46
<i>Battery Stretching Techniques</i>	46
Sleep Mode Switching	46
Power Sequencing	46
<i>Multiple Regulators Provide Isolation</i>	46
Thermal Management	47
<i>A Thermal Primer</i>	47
Thermal Parameters	47
Thermal/Electrical Analogy	47
<i>Calculating Thermal Parameters</i>	48
Calculating Maximum Allowable Thermal Resistance	49
<i>Why A Maximum Junction Temperature?</i>	49
<i>Heat Sink Charts for High Current Regulators</i>	50
<i>Thermal Examples</i>	51
<i>Heat Sink Selection</i>	52
<i>Reading Heat Sink Graphs</i>	52
<i>Power Sharing Resistor</i>	53

<i>Multiple Packages on One Heat Sink</i>	54
Paralleled Devices on a Heat Sink Example	55
<i>Heat Sinking Surface Mount Packages</i>	56
Determining Heat Sink Dimensions	56
SO-8 Calculations:	57
Comments	58
Linear Regulator Troubleshooting Guide	59
Section 4. Linear Regulator Solutions	60
Super β PNP™ Regulators	60
<i>Super beta PNP Circuitry</i>	61
<i>Dropout Voltage</i>	61
<i>Ground Current</i>	62
<i>Fully Protected</i>	62
Current Limiting	62
Overtemperature Shutdown	62
Reversed Input Polarity	62
Overvoltage Shutdown	63
<i>Variety of Packages</i>	63
<i>Why Choose Five Terminal Regulators?</i>	63
<i>Compatible Pinouts</i>	63
<i>Stability Issues</i>	64
<i>Paralleling Bipolar Regulators</i>	64
Micrel's Unique "Super LDO™"	66
<i>Micrel's Super LDO Family</i>	66
<i>The MIC5156</i>	66
<i>The MIC5157 and MIC5158</i>	66
<i>3.3V, 10A Regulator Application</i>	66
<i>Comparison With Monolithics</i>	67
Similarities to Monolithics	67
Differences from Monolithics	67
<i>Unique Super LDO Applications</i>	67
Super High-Current Regulator	67
Selecting the Current Limit Threshold	69
Sense Resistor Power Dissipation	69
Kelvin Sensing	69
<i>Alternative Current Sense Resistors</i>	69
<i>Overcurrent Sense Resistors from PC Board Traces</i>	69
Resistor Design Method	70
Design Example	70
Calculate Sheet Resistance	71
Calculate Minimum Trace Width	71
Calculate Required Trace Length	71
Resistor Layout	71
Thermal Considerations	71
<i>Design Aids</i>	71
<i>Highly Accurate Current Limiting</i>	71
<i>Protecting the Super LDO from Long-Term Short Circuits</i>	71

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.