

ELMB current limitation and thermal protection

The ELMB contains three on-board low drop voltage regulators MICREL MIC5203 [1], [2]. The purpose of these are in addition to provide stable operating voltages for each of the parts of the ELMB also to provide protection such as current limitation and over-temperature shutdown. This is necessary when operating the ELMB in radiation environment where there is a risk for Single Event Latch-ups (SEL).

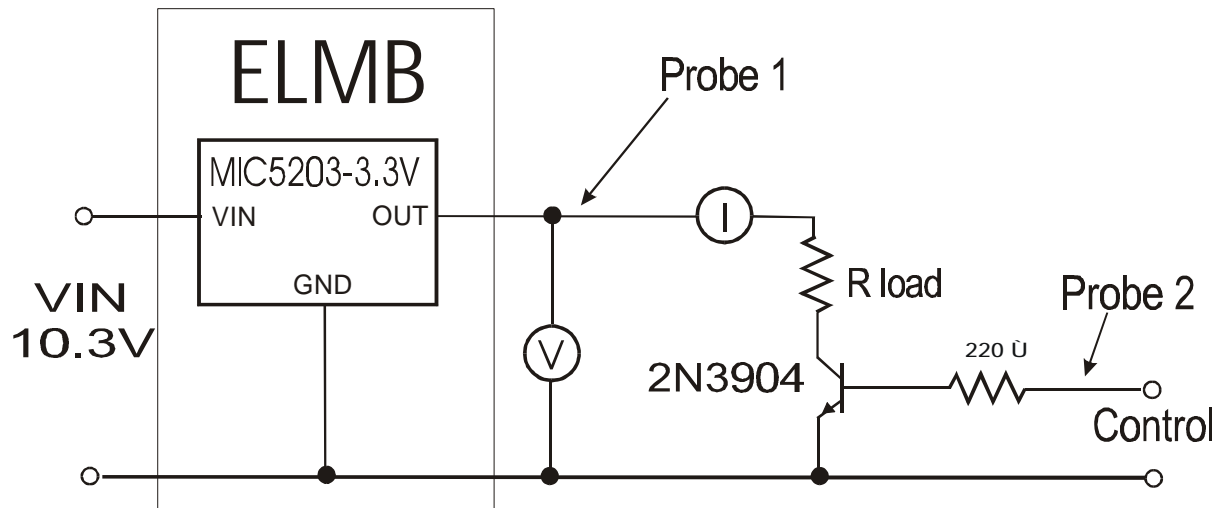


Figure 1 Test circuit

The circuit in Figure 1 has been used to measure the performance of the ELMB protection on the digital power supply. In addition to the normal current consumption of about 15 mA an extra load current is applied via a transistor and load resistor. The transient voltage change is measured with an oscilloscope probe 1. The average DC load current and output load voltage are measured with a DVMs.

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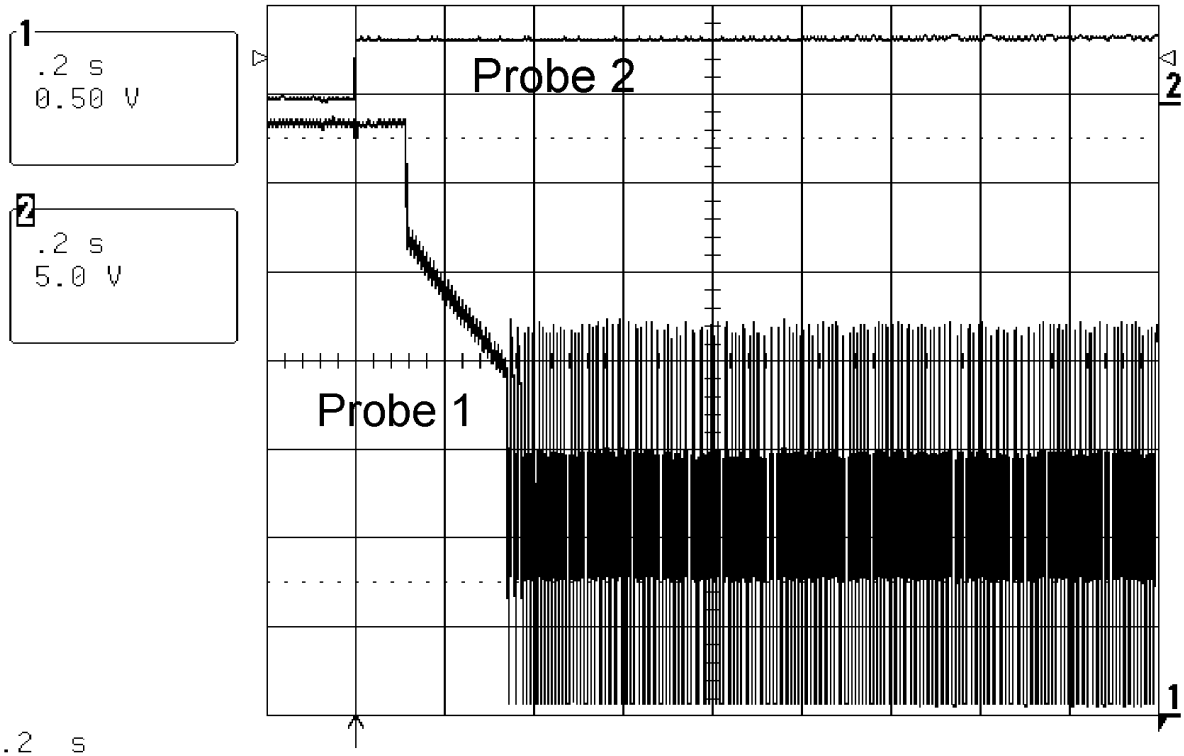


Figure 2 The output voltage change of the ELMB with an extra load of 62 mA. The x-axis is 0.2s per div and the Y-axis of the probe 1 0.5V and probe 2 5V/div.

Example 1

An external load of a total of 53 ohms is applied. This corresponds to a total current of 82 mA and an instantaneous power dissipation of 0.57 W in the regulator. As seen from Figure 2 the output voltage remains constant for 0.1s after the extra load has been applied. But thereafter the output voltage drops fast to 2.7V and then a further 0.7 V during 0.25 s. The first thermal shut-off occurs after about 0.35s. This reduces the output voltage less than 0.1V. From that moment the regulator cool-downs. It takes about approximate 2 ms until the regulator has cooled-down and it can turn on again. As the load of 53 ohms is still applied a continuous power on off cycling will occur as shown in Figure 3. The average output voltage is 1.89 V and the current in the average current 36 mA. This corresponds to power dissipation in the regulator of about 300 mW, while the power dissipation in the load is 68 mW.

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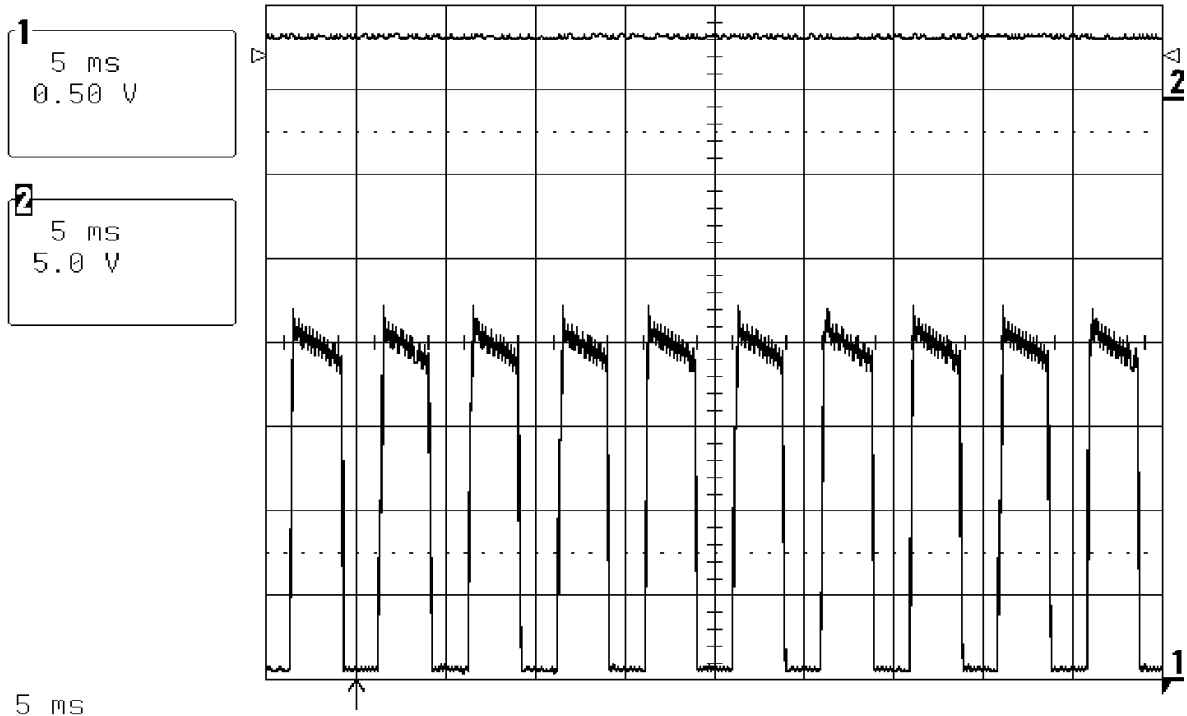


Figure 3 The steady-state behavior of the MIC5203.

Example 2

In order to simulate a higher load current a total resistor of 11 ohms was applied. This would give an overload current of 300 mA and a power dissipation of 2.1W in the regulator. Figure 4 shows the behavior of the regulator for such a load. The current is reduced immediately to about 150 mA and then the thermal regulation turns off the regulator after about 180 ms. The steady state power dissipation is shown in Figure 5. The average voltage is 0.38V with a current of 35 mA. This corresponds to the regulator power dissipation of 350 mW. The power dissipated in the external load is only 13 mW.

Discussion

The internal thermal shutdown limits the power dissipation internal in the MIC5203 to about 350mW when it is mounted on the ELMB printed circuit board. The thermal shutdown circuit of the regulator determines the steady state current. In these examples with an external power supply voltage of 10V the DC currents are limited 35 mA. The maximum instantaneous current, which can be drawn by an overload, is about 150mA. This is reduced to the steady current limit in a time of about 0.2 sec. The integrated circuits on the ELMB are under these condition fully protected and substantial overheating can not happen. It is also unlikely that an ELMB would influence the operations of other ELMBs on the same CAN branch.

The SEE radiation tests done on the ELMB so far (up to level of about $6 \cdot 10^{11}$ hadrons/cm²) have shown a few SEL but no catastrophic effects of a latch-up.

References

[1] MIC5203 data sheet, September 1998.

[2] Designing with LDO Regulators, Section 4, p 61 to 63.

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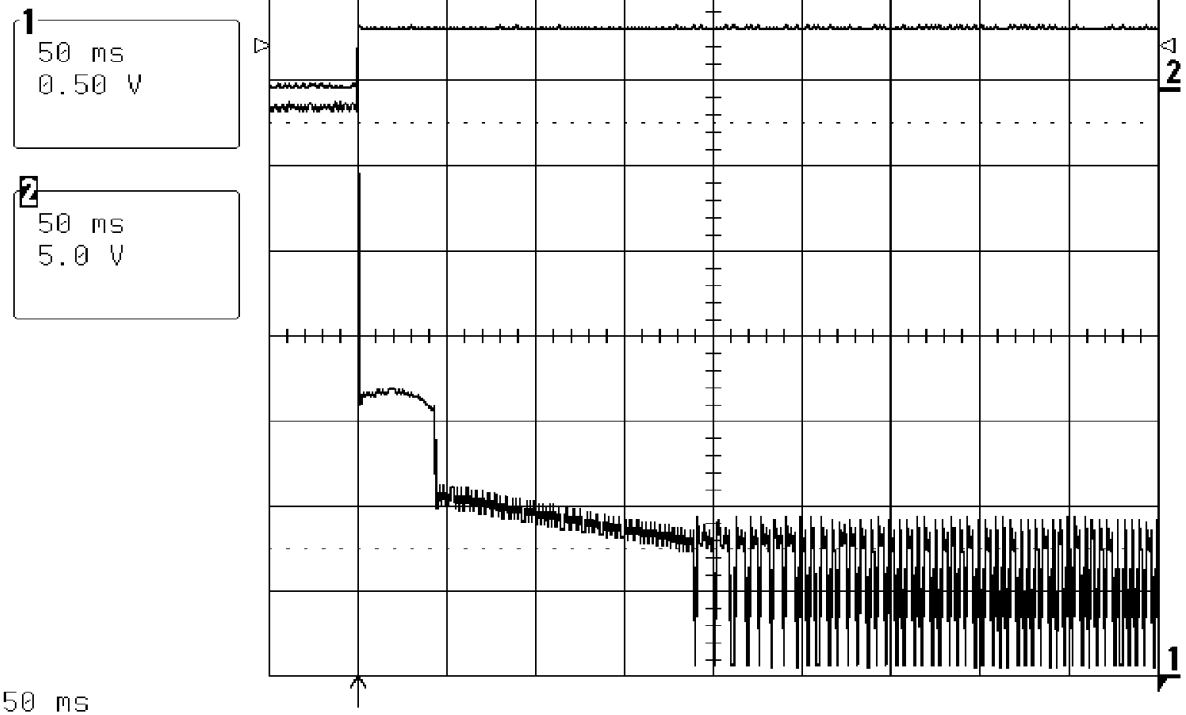


Figure 4 Behavior of the MIC5203 for a load of 2.1W. The x-scale is 50 ms/div.

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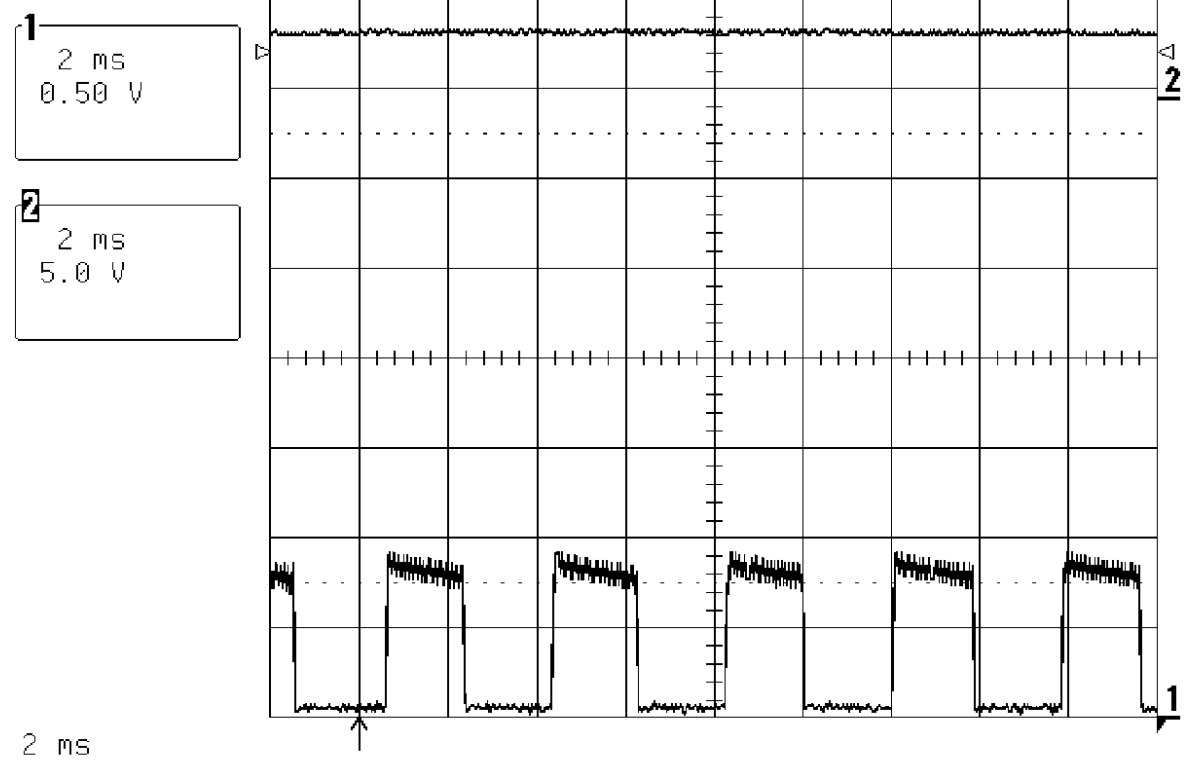


Figure 5 The resulting steady state thermal regulation for a load of 11 ohms (300 mA). The current is limited to 150 mA and the power to 13 mW.

General Description

The MIC5203 is a μCap™ 80mA linear voltage regulator with very low dropout voltage (typically 20mV at light loads and 300mV at 80mA) and very low ground current (225μA at 20mA output), offering better than 3% initial accuracy with a logic-compatible enable input.

The μCap™ regulator design is optimized to work with low-value, low-cost ceramic capacitors. The outputs typically require only 0.47μF of output capacitance for stability.

Designed especially for hand-held, battery-powered devices, the MIC5203 can be controlled by a CMOS or TTL compatible logic signal. When disabled, power consumption drops nearly to zero. If on-off control is not required, the enable pin may be tied to the input for 3-terminal operation. The ground current of the MIC5203 increases only slightly in dropout, further prolonging battery life. Key MIC5203 features include current limiting, overtemperature shutdown, and protection against reversed battery.

The MIC5203 is available in 2.8V, 3.0V, 3.3V, 3.6V, 3.8V, 4.0V, 4.5V, 4.75V, and 5.0V fixed voltages. Other voltages are available; contact Micrel for details.

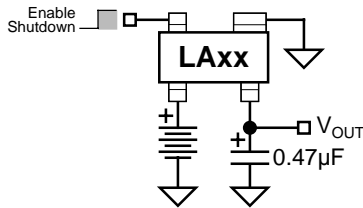
Features

- Tiny 4-lead and 5-lead surface-mount packages
- Wide Selection of output voltages
- Guaranteed 80mA output
- Low quiescent current
- Low dropout voltage
- Tight load and line regulation
- Low temperature coefficient
- Current and thermal limiting
- Reversed input polarity protection
- Zero off-mode current
- Logic-controlled shutdown
- Stability with low-ESR ceramic capacitors

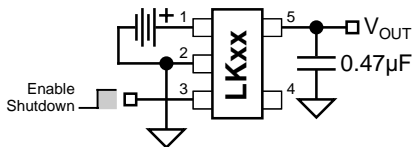
Applications

- Cellular telephones
- Laptop, notebook, and palmtop computers
- Battery-powered equipment
- Bar code scanners
- SMPS post-regulator/dc-to-dc modules
- High-efficiency linear power supplies

Typical Applications



SOT-143 Version



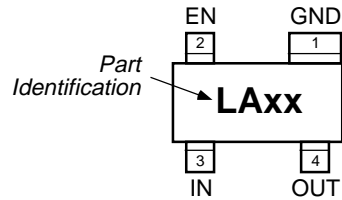
SOT-23-5 Version

Ordering Information

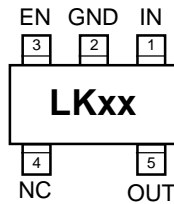
| Part Number | Marking | Voltage | Junction Temp. Range | Package |
|----------------|---------|---------|----------------------|----------|
| MIC5203-3.0BM4 | LA30 | 3.0V | -40°C to +125°C | SOT-143 |
| MIC5203-3.3BM4 | LA33 | 3.3V | -40°C to +125°C | SOT-143 |
| MIC5203-3.6BM4 | LA36 | 3.6V | -40°C to +125°C | SOT-143 |
| MIC5203-3.8BM4 | LA38 | 3.8V | -40°C to +125°C | SOT-143 |
| MIC5203-4.0BM4 | LA40 | 4.0V | -40°C to +125°C | SOT-143 |
| MIC5203-4.5BM4 | LA45 | 4.5V | -40°C to +125°C | SOT-143 |
| MIC5203-4.7BM4 | LA47 | 4.75V | -40°C to +125°C | SOT-143 |
| MIC5203-5.0BM4 | LA50 | 5.0V | -40°C to +125°C | SOT-143 |
| MIC5203-2.8BM5 | LA28 | 2.8V | -40°C to +125°C | SOT-23-5 |
| MIC5203-3.0BM5 | LK30 | 3.0V | -40°C to +125°C | SOT-23-5 |
| MIC5203-3.3BM5 | LK33 | 3.3V | -40°C to +125°C | SOT-23-5 |
| MIC5203-3.6BM5 | LK36 | 3.6V | -40°C to +125°C | SOT-23-5 |
| MIC5203-3.8BM5 | LK38 | 3.8V | -40°C to +125°C | SOT-23-5 |
| MIC5203-4.0BM5 | LK40 | 4.0V | -40°C to +125°C | SOT-23-5 |
| MIC5203-4.5BM5 | LK45 | 4.5V | -40°C to +125°C | SOT-23-5 |
| MIC5203-4.7BM5 | LK47 | 4.75V | -40°C to +125°C | SOT-23-5 |
| MIC5203-5.0BM5 | LK50 | 5.0V | -40°C to +125°C | SOT-23-5 |

Other voltages available. Contact Micrel for details.

Pin Configuration



SOT-143 (M4)



SOT-23-5 (M5)

Pin Description

| Pin Number SOT-143 | Pin Number SOT-23-5 | Pin Name | Pin Function |
|-----------------------|------------------------|----------|--|
| 1 | 2 | GND | Ground |
| 2 | 3 | EN | Enable (Input): TTL/CMOS compatible control input. Logic high = enabled; logic low or open = shutdown. |
| 3 | 1 | IN | Supply Input |
| | 4 | NC | Not internally connected. |
| 4 | 5 | OUT | Regulator Output |

Absolute Maximum Ratings (Note 1)

| | | |
|--------------------------------------|-------|--------------------|
| Input Supply Voltage (V_{IN}) | | -20V to +20V |
| Enable Input Voltage (V_{EN}) | | -20V to +20V |
| Power Dissipation (P_D) | | Internally Limited |
| Storage Temperature Range (T_S) | | -60°C to +150°C |
| Lead Temperature (Soldering, 5 sec.) | | 260°C |

Operating Ratings (Note 2)

| | | |
|--------------------------------------|-------|-----------------|
| Input Voltage (V_{IN}) | | 2.5V to 16V |
| Enable Input Voltage (V_{EN}) | | 0V to V_{IN} |
| Junction Temperature Range | | -40°C to +125°C |
| Thermal Resistance (θ_{JA}) | | Note 3 |

Electrical Characteristics

$V_{IN} = V_{OUT} + 1V$; $I_L = 1mA$; $C_L = 0.47\mu F$; $V_{EN} \geq 2.0V$; $T_J = 25^\circ C$, **bold** values indicate $-40^\circ C \leq T_J \leq +125^\circ C$; unless noted.

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|-------------------------|-----------------------------------|--|----------|-----------|-------------------|-----------------|
| V_O | Output Voltage Accuracy | | -3 -4 | | 3 4 | % % |
| $\Delta V_O/\Delta T$ | Output Voltage Temp. Coefficient | Note 4 | | 50 | 200 | ppm/ $^\circ C$ |
| $\Delta V_O/V_O$ | Line Regulation | $V_{IN} = V_{OUT} + 1V$ to 16V | | 0.008 | 0.3 0.5 | % % |
| $\Delta V_O/V_O$ | Load Regulation | $I_L = 0.1mA$ to 80mA, Note 5 | | 0.08 | 0.3 0.5 | % % |
| $V_{IN}-V_O$ | Dropout Voltage, Note 6 | $I_L = 100\mu A$ | | 20 | | mV |
| | | $I_L = 20mA$ | | 200 | 350 | mV |
| | | $I_L = 50mA$ | | 250 | | mV |
| | | $I_L = 80mA$ | | 300 | 600 | mV |
| I_Q | Quiescent Current | $V_{EN} \leq 0.4V$ (shutdown) | | 0.01 | 10 | μA |
| I_{GND} | Ground Pin Current, Note 7 | $I_L = 100\mu A$, $V_{EN} \geq 2.0V$ (active) | | 180 | | μA |
| | | $I_L = 20mA$, $V_{EN} \geq 2.0V$ (active) | | 225 | 750 | μA |
| | | $I_L = 50mA$, $V_{EN} \geq 2.0V$ (active) | | 850 | | μA |
| | | $I_L = 80mA$, $V_{EN} \geq 2.0V$ (active) | | 1800 | 3000 | μA |
| I_{GNDDO} | Ground Pin Current at Dropout | $V_{IN} = V_{OUT(nominal)} - 0.5V$, Note 7 | | 200 | 300 | μA |
| I_{LIMIT} | Current Limit | $V_{OUT} = 0V$ | | 180 | 250 | mA |
| $\Delta V_O/\Delta P_D$ | Thermal Regulation | Note 8 | | 0.05 | | %/W |

Enable Input

| | | | | | | |
|----------|----------------------------|--------------------|------------|------|------------|---------|
| V_{IL} | Enable Input Voltage Level | logic Low (off) | | | 0.6 | μA |
| V_{IH} | | logic high (on) | 2.0 | | | μA |
| I_{IL} | Enable Input Current | $V_{IL} \leq 0.6V$ | | 0.01 | 1 | μA |
| I_{IH} | | $V_{IH} \geq 2.0V$ | | 15 | 50 | μA |

Note 1. Exceeding the absolute maximum rating may damage the device.

Note 2. The device is not guaranteed to function outside its operating rating.

Note 3: The maximum allowable power dissipation at any T_A (ambient temperature) is $P_{D(max)} = (T_{J(max)} - T_A) \div \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The θ_{JA} is 250 $^\circ C/W$ for the SOT-143 and 220 $^\circ C/W$ for the SOT-23-5 mounted on a printed circuit board.

Note 4: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

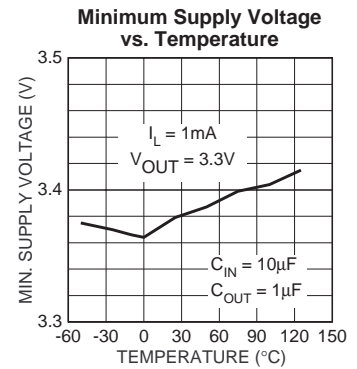
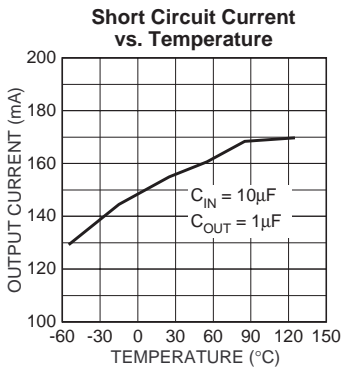
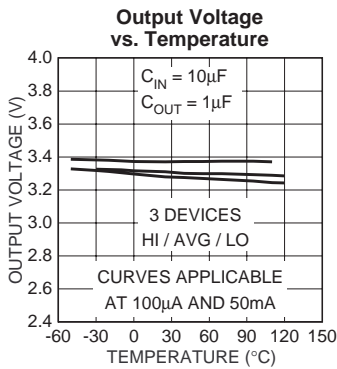
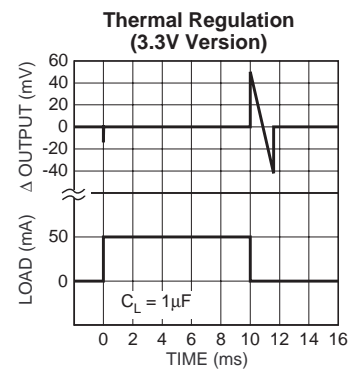
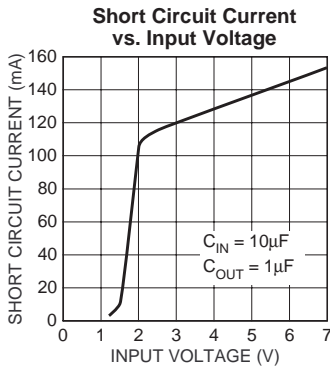
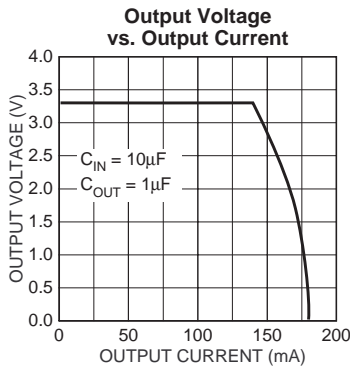
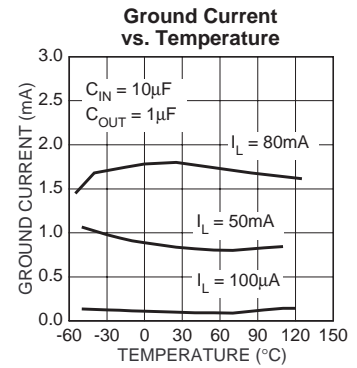
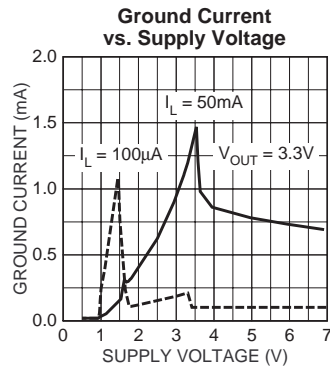
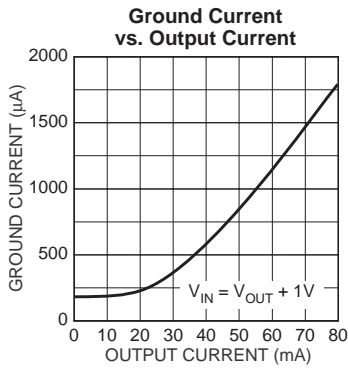
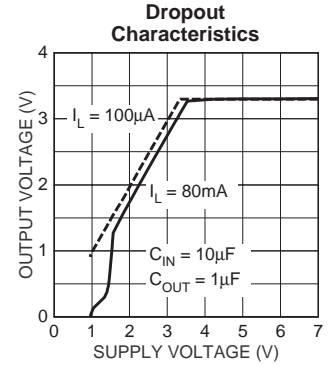
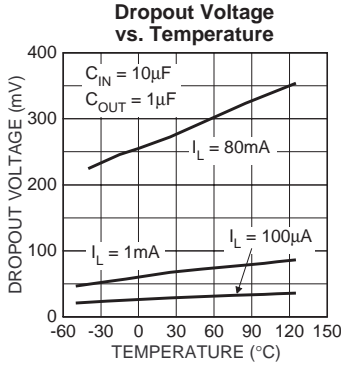
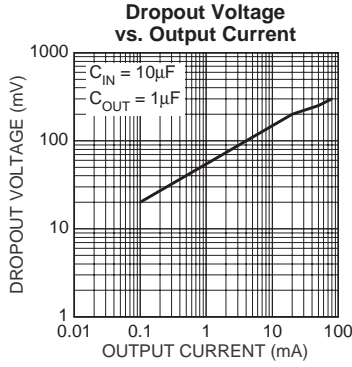
Note 5: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 150mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

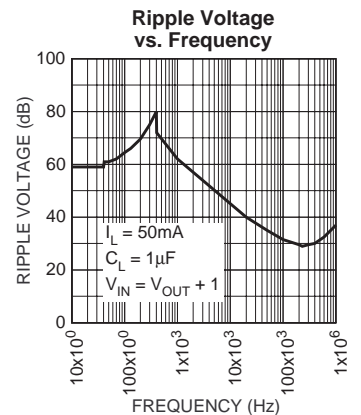
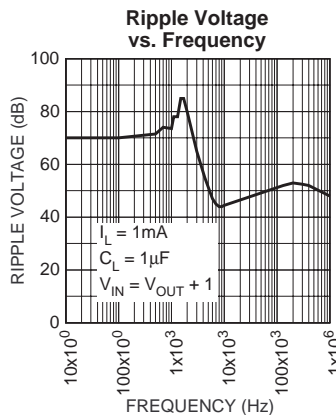
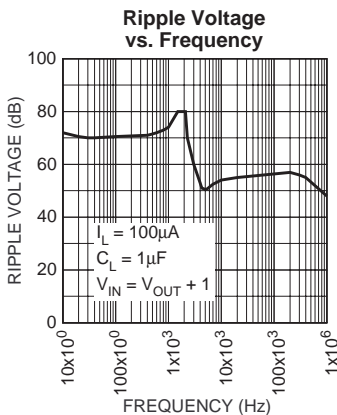
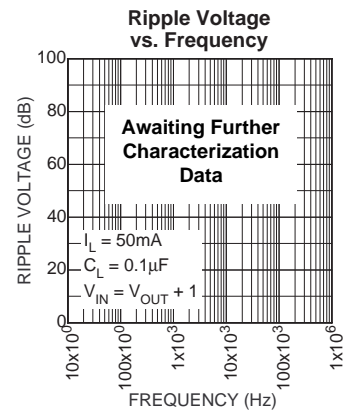
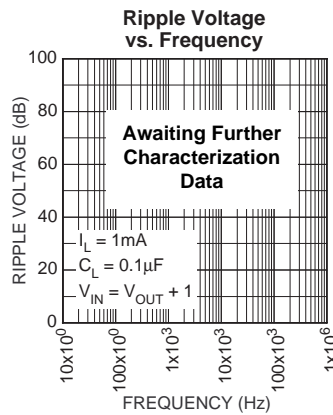
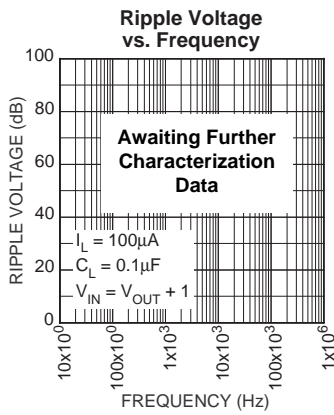
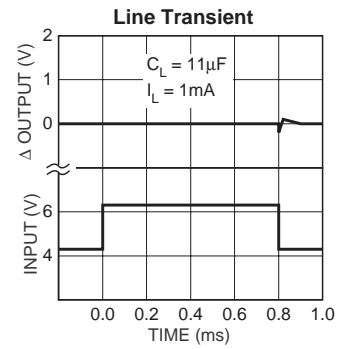
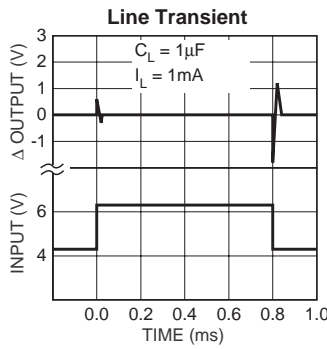
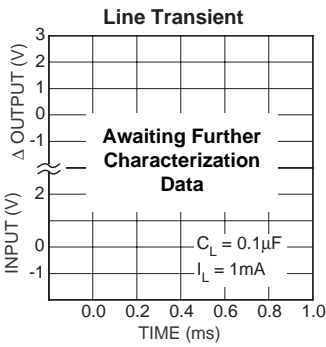
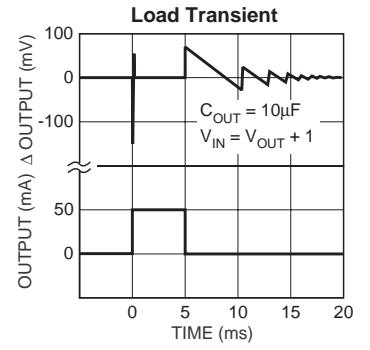
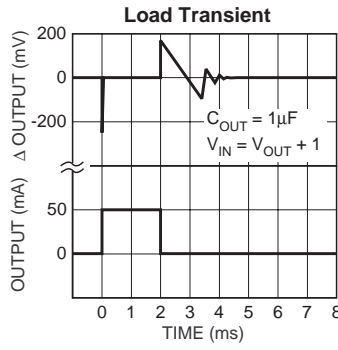
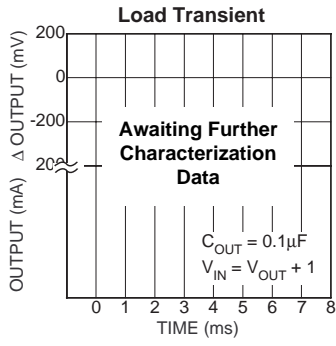
Note 6: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

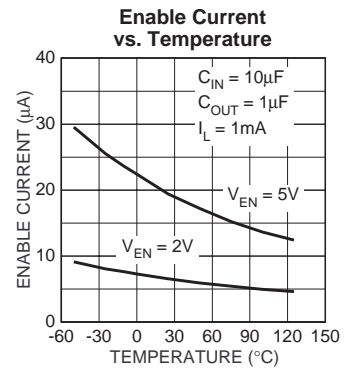
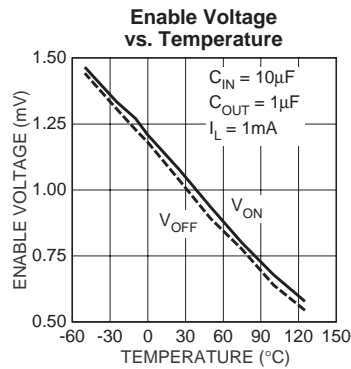
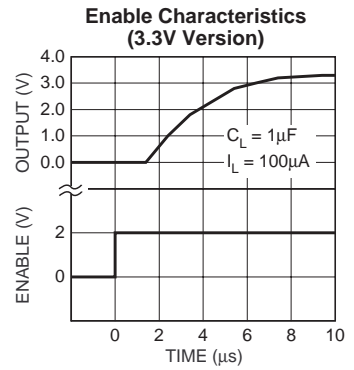
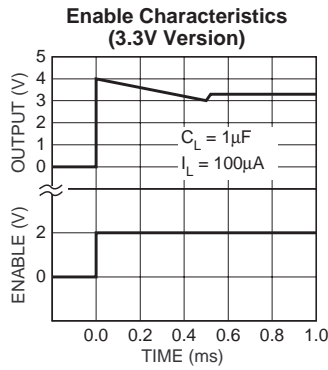
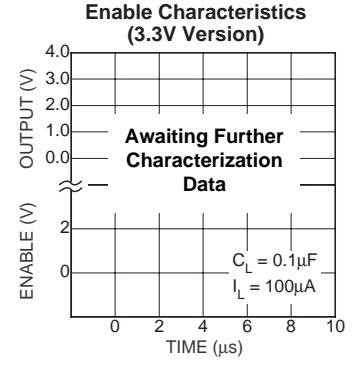
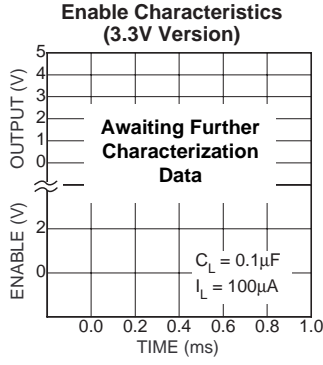
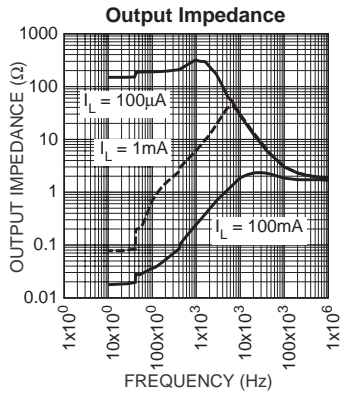
Note 7: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

Note 8: Thermal regulation is defined as the change in output voltage at a time "t" after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 150mA load pulse at $V_{IN} = 16V$ for $t = 10ms$.

Typical Characteristics







Applications Information

Input Capacitor

A 0.1 μ F capacitor should be placed from IN to GND if there is more than 10 inches of wire between the input and the ac filter capacitor or when a battery is used as the input.

Output Capacitor

Typical PNP based regulators require an output capacitor to prevent oscillation. The MIC5203 is ultrastable, requiring only 0.47 μ F of output capacitance for stability. The regulator is stable with all types of capacitors, including the tiny, low-ESR ceramic chip capacitors. The output capacitor value can be increased without limit to improve transient response.

The capacitor should have a resonant frequency above 500kHz. Ceramic capacitors work, but some dielectrics have poor temperature coefficients, which will affect the value of the output capacitor over temperature. Tantalum capacitors are much more stable over temperature, but typically are larger and more expensive. Aluminum electrolytic capacitors

will also work, but they have electrolytes that freeze at about -30°C . Tantalum or ceramic capacitors are recommended for operation below -25°C .

No-Load Stability

The MIC5203 will remain stable and in regulation with no load (other than the internal voltage divider) unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications.

Enable Input

The MIC5203 features nearly zero off-mode current. When EN (enable input) is held below 0.6V, all internal circuitry is powered off. Pulling EN high (over 2.0V) re-enables the device and allows operation. EN draws a small amount of current, typically 15 μ A. While the logic threshold is TTL/CMOS compatible, EN may be pulled as high as 20V, independent of V_{IN} .

Section 4. Linear Regulator Solutions

Super β PNP™ Regulators

Micrel's easy to use Super β PNP™ LDO monolithic regulators deliver highly accurate output voltages and are fully protected from fault conditions. Their maximum output currents range from 80mA to 7.5A. They are available in numerous fixed voltages, and most families offer adjustable versions.

Micrel's monolithic linear regulator family appears below, listed by increasing output current capability.

-
- MIC5203 — 80mA regulator in the tiny SOT-143 package. Fixed output voltages of 2.85, 3.0, 3.3, 3.6, 3.8, 4.0, 4.75, and 5.0V are available.
- LP2950 — 100mA fixed 3.3, 4.85, and 5.0V regulator available in the TO-92 package.
- LP2951 — 100mA fixed 5.0V and adjustable regulator available in the SO-8 package.
- MIC5200 — 100mA regulator available in SO-8 and SOT-223 packages. Fixed output voltages of 3.0, 3.3, 4.85, and 5.0V are available.
- MIC5202 — dual 100mA version of the '5200, available in the SO-8 package.
- MIC5205 — 150mA low-noise fixed and adjustable regulator supplied in the small SOT-23-5 package.
- MIC5206 — 150mA low-noise regulator supplied in the small SOT-23-5 or MSOP-8 packages.
- MIC5207 — 180mA low-noise regulator supplied in the small SOT-23-5 or TO-92 packages.
- MIC2950 — 150mA fixed 3.3, 4.85, and 5.0V regulator available in the TO-92 package.
- MIC2951 — 150mA fixed 5.0V and adjustable regulator available in the SO-8 package.
- MIC5201 — 200mA regulator available in SO-8 and SOT-223 packages. Fixed output voltages of 3.0, 3.3, 4.85, and 5V, plus an adjustable version are available.
- MIC2920A — family of 400mA regulators in TO-220, TO-263-3, SOT-223, and SO-8 packages. Fixed output voltages of 3.3V, 4.85V, 5V, and 12V plus three adjustable versions are available.
- MIC2937A — family of 750mA regulators in TO-220 and TO-263 packages. Fixed output voltages of 3.3V, 5V, and 12V, plus two adjustable versions are available.
- MIC2940A — 1250mA regulators in TO-220 and TO-263 packages with fixed output voltages of 3.3V, 5V, and 12V. The MIC2941A is an adjustable version.
- MIC29150 — family of 1.5A regulators in TO-220 and TO-263 packages. Fixed output voltages of 3.3V, 5V, and 12V, plus two adjustable versions are available.
- MIC29300 — family of 3A regulators in TO-220 and TO-263 packages. Fixed output voltages of 3.3V, 5V, and 12V, plus two adjustable versions are available.
- MIC29310 — low-cost 3A regulator with 3.3 and 5V fixed outputs in a TO-220 package. The MIC29312 is an adjustable version.
- MIC29500 — family of 5A regulators in TO-220, and TO-263 packages. Fixed output voltages of 3.3V and 5V, plus two adjustable versions are available.
- MIC29510 — low-cost 5A regulator with 3.3 and 5V fixed outputs in a TO-220 package. The MIC29512 is an adjustable version.
- MIC29710 — low-cost 7.5A regulator with 3.3 and 5V fixed outputs in a TO-220 package. The MIC29712 is an adjustable version.
- MIC29750 — 7.5A regulator in a TO-247 power package with 3.3 and 5V fixed outputs. The MIC29752 is an adjustable version.

Micrel's medium and high-current regulators (400mA and higher output current capability) have a part numbering code that denotes the additional features offered. The basic family number, ending in "A" or "0" denotes the easy-to-use three-pin fixed voltage regulator.

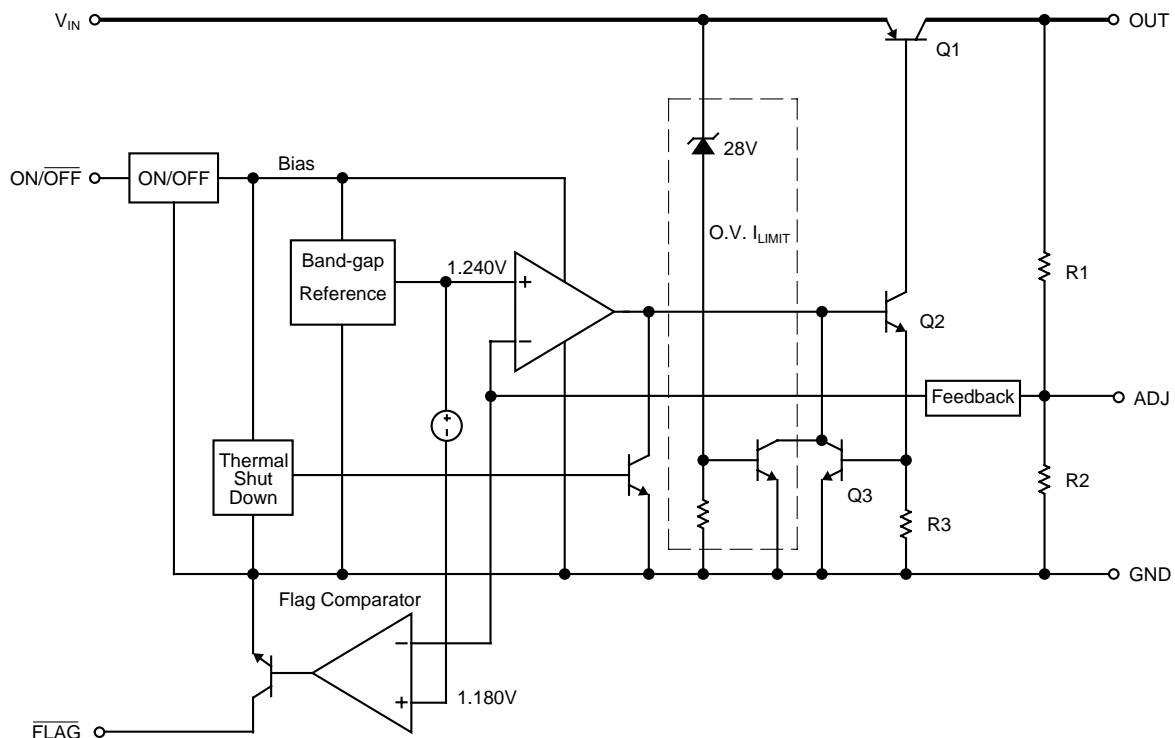


Figure 4-1. Super β PNP™ Regulator Simplified Schematic Diagram

- Part numbers ending in “1” are five-pin fixed devices with a digital control pin for turning the regulator ON or OFF and an Error Flag output that signals when the output is not in regulation.
- Part numbers ending in “2” are adjustable parts with ON/OFF control.
- Devices ending with “3” are adjustables with an Error Flag.

Super β PNP Circuitry

The simplified schematic diagram of Micrel’s medium and high current monolithic LDOs appears as Figure 4-1. The high current path from input to output through the pass transistor is in bold. The bandgap reference and all other circuitry is powered via the Enable Circuit, which allows for “zero” current draw when disabled. The reference voltage is compared to the sampled output voltage fed back by R1 and R2. If this voltage is less than the bandgap reference, the op amp output increases. This increases the current through driver transistor Q2, which pulls down on the base of Q1, turning it on harder. If Q1’s base current rises excessively, the voltage drop across R3 enables Q3, which in turn limits the current through Q2. Die temperature is monitored, and if it becomes

excessive, the thermal shutdown circuit activates, clamping the base of Q2 and shutting down Q1. The flag circuit looks at the output voltage sample and compares it to a reference set 5% lower. If the sample is even lower, the flag comparator saturates the open collector flag transistor, signaling the fault condition.

Dropout Voltage

The Super β PNP family of low-dropout regulators offers typical dropout voltages of only 300mV across the output current range. This low dropout is achieved by using large and efficient multicelled PNP output transistors, and operating them in their high-beta range well below their capacity. Dropout voltage in the Super β PNP regulators is determined by the saturation voltage of the PNP pass element. As in all bipolar transistors, the saturation voltage is proportional to the current through the transistor. At light loads, the dropout voltage is only a few tens of millivolts. At moderate output currents, the dropout rises to 200 to 300mV. At the full rated output, the typical dropout voltage is approximately 300mV for most of the families. Lower cost versions have somewhat higher dropout at full load, generally in the 400 to

500mV range. The data sheet for each device graphs typical dropout voltage versus output current.

Ground Current

Micrel's Super β PNP process allows these high current devices to maintain very high transistor beta—on the order of 100 at their full rated current. This contrasts with competitive PNP devices that suffer with betas in the 10 to 30 range. This impacts regulator designs by reducing wasteful ground current. Micrel's beta of 100 translates into typical full load ground currents of only 1% of your output. The data sheet for each device graphs typical ground current versus output current.

When linear regulators approach dropout, generally due to insufficient input voltage, base drive to the pass transistor increases to fully saturate the transistor. With some older PNP regulators, the ground current would skyrocket as dropout approached. Micrel's Super β PNP regulators employ saturation detection circuitry which limits base drive when dropout-induced saturation occurs, limiting ground current.

Fully Protected

Micrel regulators are survivors. Built-in protection features like current limiting, overtemperature shutdown, and reversed-input polarity protection allow LDO survival under otherwise catastrophic situations. Other protection features are optionally available, such as overvoltage shutdown and a digital error flag.

Current Limiting

Current limiting is the first line of defense for a regulator. It operates nearly instantaneously in the event of a fault, and keeps the internal transistor, its wire bonds, and external circuit board traces from fusing in the event of a short circuit or extremely heavy output load. The current limit operates by linearly clamping the output current in case of a fault. For example, if a MIC29150 with a 2A current limit encounters a shorted load, it will pass up to 2A of current into that load. The resulting high power dissipation (2A multiplied by the entire input voltage) causes the regulator's die temperature to rise, triggering the second line of defense, overtemperature shutdown.

Overtemperature Shutdown

As the output fault causes internal dissipation and die temperature rise, the regulator approaches its operating limits. At a predetermined high temperature, the regulator shuts off its pass element, bringing output current and power dissipation to zero. The hot die begins cooling. When its temperature drops below an acceptable temperature threshold, it automatically re-enables itself. If the load problem has been addressed, normal operation resumes. If the short persists, the LDO will begin sourcing current, will heat up, and eventually will turn off again. This sequence will repeat until the load is corrected or input power is removed. Although operation at the verge of thermal shutdown is not recommended, Micrel has tested LDOs for several million ON/OFF thermal cycles without undue die stress. In fact, during reliability testing, regulators are burned-in at the thermal shutdown-cycle limit.

Reversed Input Polarity

Protection from reversed input polarity is important for a number of reasons. Consumer products using LDOs with this feature survive batteries inserted improperly or the use of the wrong AC adapter. Automotive electronics must survive improper jump starting. All types of systems should last through initial production testing with an incorrectly inserted (backward) regulator. By using reversed input protected regulators, both the regulator and its load are protected against reverse polarity, which limits reverse current flow.

This feature may be simulated as an ideal diode, *with zero forward voltage drop*, in series with the output. Actually, a small current flows from the input pin to ground through the voltage divider network, but this may generally be neglected. Measured data from Super β PNP regulators with a 100 Ω resistor from output to ground follows:

| <u>Input Voltage (V)</u> | <u>Load Current (mA)</u> |
|--------------------------|--------------------------|
| 0 | 0 |
| -5 | 0 |
| -10 | 0 |
| -15 | -2.0 |
| -20 | -6.9 |
| -25 | -7.8 |
| -30 | -14 |

Although the devices were tested to -30V for this table without any failure, the reverse-polarity specification ranges only to -20V.