Application Note 9

Design Considerations for 5V to 3.3V Pass Regulators

By Bob Wolbert

General Description

The rise of 3.3V logic and memory components in personal computer systems has created demand for 3.3V power supplies. Several options exist for the computer system designer. One of these options is to provide both 3.3V and 5.0V from the main system power supply and use a switch matrix for voltage selection (see Application Hint 15 for representative circuitry). Two drawbacks to this technique exist: (1) the extra 3.3V output costs money; and (2), at current levels above about 1A, the MOSFETs used in the 3.3V portion of the matrix require exceptionally low ON resistance to maintain output tolerance and are quite expensive. Another option uses the existing high current 5V supply and employs a low drop-out (LDO) linear regulator to provide 3.3V. This is a low cost option, requiring only short design work and little motherboard space. Linear regulators provide clean, accurate output and do not radiate RFI, so government certification is not jeopardized. They are fast starting, and may provide ON/OFF control and an error flag that indicates power system trouble. At low current levels, thermal considerations are not difficult; however, at currents of 3.5 to 5 amperes, the resulting heat may be troublesome. This note discusses the LDO option, including choosing between simple three terminal regulators and full-featured five terminal regulators, and provides formulas, calculations, and a selection of commercial heat sinks for powering 3.3V logic circuitry requiring up to 5 amps from a standard +5V supply. Additionally, a “trick” for reducing heat sink requirements by distributing power dissipation with a series resistor is discussed.

Why Choose Five Terminal Regulators?

What do the extra pins of the five pin linear regulators provide? After all, three terminal regulators give Input, Output, and Ground; what else is necessary? Five terminal devices allow the system designer to monitor power quality to the load and digitally switch the supply ON and OFF. Power quality is monitored by a flag output. When the output voltage is within a few percent of its desired value, the flag is high, indicating "Good". If the output drops, because of either low input voltage to the regulator or an over-current condition, the flag drops to signal a fault condition. A controller can monitor this output and make decisions regarding the system's readiness. For example, at initial power-up, the flag will instantaneously read high (if pulled up to an external supply), but as soon as the input supply to the regulator reaches about 2V, the flag pulls low. It stays low until the regulator output nears its desired value. With the MIC29150 family of low drop-out linear regulators, the flag rises when the output voltage reaches about 97% of the desired value. In a 3.3V system, the flag indicates "power good" with V_{OUT} = 3.2V.

Digital power control allows “sleep” mode operation and results in better energy efficiency. The ENABLE input of the MIC29150 family is TTL and 5V or 3.3V CMOS compatible. When this input is pulled above approximately 1.4V, the regulator is activated. A special feature of this regulator family is *zero power consumption* when inactive. Whenever the digital control input is low, all internal circuitry is biased OFF. (A tiny leakage current, measured in nanoamperes, may flow).

Three terminal regulators are used whenever ON/OFF control is not necessary and processing power is not available to use the flag output information. Three terminal regulators need only a single output filter capacitor so design effort is minimal.

Five terminal regulators provide all the functionality of three pin devices PLUS allow power supply quality monitoring and ON/OFF switching for "sleep" mode applications.

Thermal Design Considerations

Micrel low drop-out (LDO) regulators are very easy to use. Only one external filter capacitor is necessary for operation so electrical design effort is minimal. In many cases, thermal design is also quite simple, due to the low drop-out characteristic of Micrel's LDOs. Unlike other linear regulators, Micrel's LDOs operate with drop-out voltages of 300mV–often less. The resulting Voltage x Current power loss can be quite small with low to moderate output current. At higher currents, however, selecting the correct heat sink is an important chore. Power dissipation in a linear regulator is:

$$P_D = [(V_{IN} - V_{OUT})\, I_{OUT}] + (V_{IN} \bullet I_{GND})$$

Where: P_D = Power dissipation
V_{IN} = Input voltage applied to the regulator
V_{OUT} = Regulator output voltage
I_{OUT} = Regulator output current
I_{GND} = Regulator biasing currents

Proper design dictates use of worst case values for all parameters. Worst case V_{IN} is high supply; in this case, 5V + 5%, or 5.25V. Worst case V_{OUT} for thermal considerations is minimum, or 3.3V – 2% = 3.234V.[1] I_{OUT} is taken at its highest steady-state value. The ground current value comes from the device's datasheet, from the graph of I_{GND} vs. I_{OUT}. Armed with this information, we calculate the thermal resistance (θ_{SA}) required of the heat sink using the following formula:

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Assuming a Micrel LDO with a maximum die temperature of 125°C in a TO-220 package with a θ_{JC} of 2°C/W and a mounting resistance (θ_{CS}) of 1°C/W[2], operating at an ambient temperature of 50°C, we get

$$\theta_{SA} = \frac{125 - 50°C}{10.5W} - (2 + 1°C/W) = \mathbf{4.1\ °C/W}$$

Performing similar calculations for 1.25A, 1.5A, 2.0A, 2.5A, 3.0A, 4.0A, and 5.0A gives the results shown in Table 1.

Regulator	I_{OUT}	P_D (W)	θ_{SA}(°C/W)
MIC29150	1.25A	2.6	25
MIC29150	1.5A	3.2	21
MIC29300	2.0A	4.2	15
MIC29300	2.5A	5.2	11
MIC29300	3.0A	6.3	8.8
MIC29500	4.0A	8.4	5.9
MIC29500	5.0A	10.5	4.1

Table 1. Micrel LDO power dissipation and heat sink requirements for various 3.3V current levels.

Table 2 shows the effect maximum ambient temperature has on heat sink thermal properties. Lower thermal resistances require physically larger heat sinks. The table clearly shows cooler running systems need smaller heat sinks, as common sense suggests.

Heat Sink Selection

With this information we may specify a heat sink. The worst case is still air (natural convection). The heat sink should be mounted so that at least 0.25 inches (about 6mm) of separation exists between the sides and top of the sink and other components or the system case. Thermal properties are maximized when the heat sink is mounted so that natural vertical motion of warm air is directed along the long axis of the sink fins.

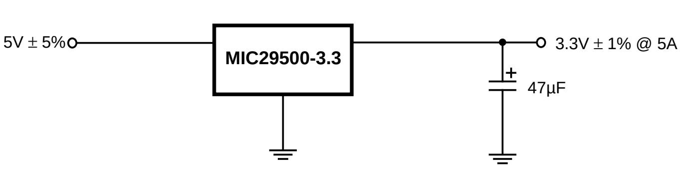

Figure 2. Using a Micrel LDO is very simple. Only an output filter capacitor is necessary. Here, 3.3V at 5A is produced from a nominal 5V input.

If we are fortunate enough to have some forced airflow, reductions in heat sink cost and space are possible by characterizing air speed–even a slow airstream significantly assists cooling. As with natural convection, a small gap allowing the airstream to pass is necessary. Fins should be located to maximize airflow along them. Orientation with respect to vertical is not important, as the airflow dominates.

Output	Ambient Temperature		
	40°C	**50°C**	**60°C**
1.5A	24°C/W	21°C/W	17°C/W
5A	5.1°C/W	4.1°C/W	3.2°C/W

Table 2. Ambient temperature affects heat sink requirements

As an example, we will select heat sinks for 1.5A and 5A outputs. We consider four airflow cases: natural convection, 200 feet/minute (1m/sec), 300 feet/minute (1.5m/sec), and 400 feet/minute (2m/sec). Table 3 shows heat sinks for these air velocities; note the rapid reduction in size and weight (fin thickness) when forced air is available. Consulting manufacturer's charts,[3,4] we see a variety of sinks are made that are suitable for our application. At 5A (10.5W worst case package dissipation) and natural convection, sinks are sizable, but at 1.5A (3.2W worst case package dissipation) and 400 feet/minute airflow, modest heat sinks are adequate.

The heat sink required for 5A applications in still air is massive and expensive. There is a better way to manage heat problems: we take advantage of the very low drop out voltage characteristic of Micrel's Super ßeta PNP™ regulators and dissipate some power externally in a series resistance.[5] By distributing the voltage drop between this low cost resistor and the regulator, we distribute the heating, and reduce the size of the regulator heat sink. Knowing the worst case voltages in the system and the peak current requirements, we select a resistor that drops a portion of the excess voltage without sacrificing performance. The maximum value of the resistor is calculated from:

$$R_{MAX} = \frac{V_{IN\ MIN} - (V_{OUT\ MAX} + V_{DO})}{I_{OUT\ PEAK} + I_{GND}}$$

Where: $V_{IN\ MIN}$ is low supply (5V – 5% = 4.75V)

$V_{OUT\ MAX}$ is the maximum output voltage across the full temperature range (3.3V + 2% = 3.366V)

V_{DO} is the worst case dropout voltage across the full temperature range (600mV)

$I_{OUT\ PEAK}$ is the maximum 3.3V load current

I_{GND} is the regulator ground current.

For our 5A output example:

$$R_{MAX} = \frac{4.75 - (3.366 + 0.6)\ V}{5 + 0.08\ A} = \frac{0.784V}{5.08A} = 0.154\Omega$$

The power drop across this resistor is

$$P_{D\ RES} = (I_{OUT\ PEAK} + I_{GND})^2 \bullet R$$

or 4.0W. This subtracts directly from the 10.5W of regulator power dissipation that occurs without the resistor, reducing regulator heat generation to 6.5W.

$$P_{D(Regulator)} = P_{D(R\ =\ 0\Omega)} - P_{D\ RES}$$

Considering 5% resistor tolerances and standard values leads us to a 0.15Ω ± 5% resistor. This produces a nominal power savings of 3.9W. With worst-case tolerances, the regulator power dissipation drops to 6.8W maximum. This heat drop reduces our heat sinking requirements for the MIC29500 significantly. We can use a smaller heat sink with a larger thermal resistance. Now, a heat sink with 8.3°C/W thermal characteristics is suitable–nearly a factor of 2 better than without the resistor. Table 4 lists representative heat sinks meeting these conditions.

For the 1.5A output application using the MIC29150, we calculate a maximum R of 0.512Ω. Using R = 0.51Ω, savings of at least 1.1W are achieved, dropping power dissipation to only 2.0W–a heat sink probably is not required. This circuit is shown in Figure 4.

Another option exists for designers of lower current systems. The MIC29150 and MIC29300 regulators are available in the surface mount derivative of the TO-220 package, the TO-263, which is soldered directly to the PC board. No separate heat sink is necessary, as copper area on the board acts as the heat exchanger. For further information, refer to Micrel's Application Hint 17, "P.C. Board Heat Sinking".

	Output Current	
Airflow	**1.5A**	**5A**
400 ft./min. (2m/sec)	Thermalloy 6049PB	Thermalloy 6232 Thermalloy 6034 Thermalloy 6391B
300 ft./min. (1.5m/sec)		AAVID 504222B AAVID 563202B AAVID 593202B AAVID 534302B Thermalloy 7021B Thermalloy 6032 Thermalloy 6234B
200 ft./min. (1m/sec)	AAVID 577002 Thermalloy 6043PB Thermalloy 6045B	AAVID 508122 AAVID 552022 AAVID 533302 Thermalloy 7025B Thermalloy 7024B Thermalloy 7022B Thermalloy 6101B
Natural Convection (no forced airflow)	AAVID 576000 AAVID 574802 592502 579302 Thermalloy 6238B Thermalloy 6038 Thermalloy 7038	AAVID 533602B (vertical) AAVID 519922B (horizontal) AAVID 532802B (vertical) Thermalloy 6299B (vertical) Thermalloy 7023 (horizontal)

Table 3. Commercial heat sinks for 1.5A and 5.0A applications

Airflow	Heat Sink Model
400 ft./min. (2m/sec)	AAVID 530700 AAVID 574802 Thermalloy 6110 Thermalloy 7137, 7140 Thermalloy 7128
300 ft./min. (1.5m/sec)	AAVID 57302 AAVID 530600 AAVID 577202 AAVID 576802 Thermalloy 6025 Thermalloy 6109 Thermalloy 6022
200 ft./min. (1m/sec)	AAVID 575102 AAVID 574902 AAVID 523002 AAVID 504102 Thermalloy 6225 Thermalloy 6070 Thermalloy 6030 Thermalloy 6230 Thermalloy 6021, 6221 Thermalloy 7136, 7138
Natural Convection (no forced airflow)	AAVID 563202 AAVID 593202 AAVID 534302 Thermalloy 6232 Thermalloy 6032 Thermalloy 6034 Thermalloy 6234

Table 4. Representative commercial heat sinks for the 5.0A output example using a series dropping resistor. Assumptions: $T_A = 50°C$, $R = 0.15\Omega \pm 5\%$, $I_{OUT\ MAX} = 5.0A$, $\theta_{JC} = 2°C/W$, $\theta_{CS} = 1°C/W$, resulting in a required $\theta_{SA} = 8.0°C/W$.

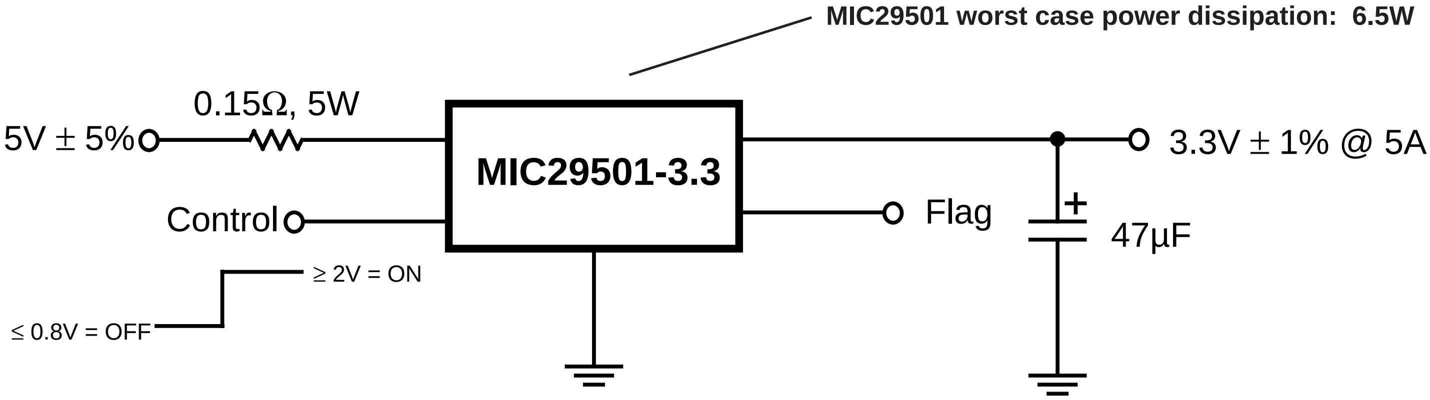

Figure 3. Producing 3.3V at 5A with minimal heat sink requirements. A 0.15Ω resistor dissipates excess power, reducing regulator heat generation. The resistor needs no heat sink.

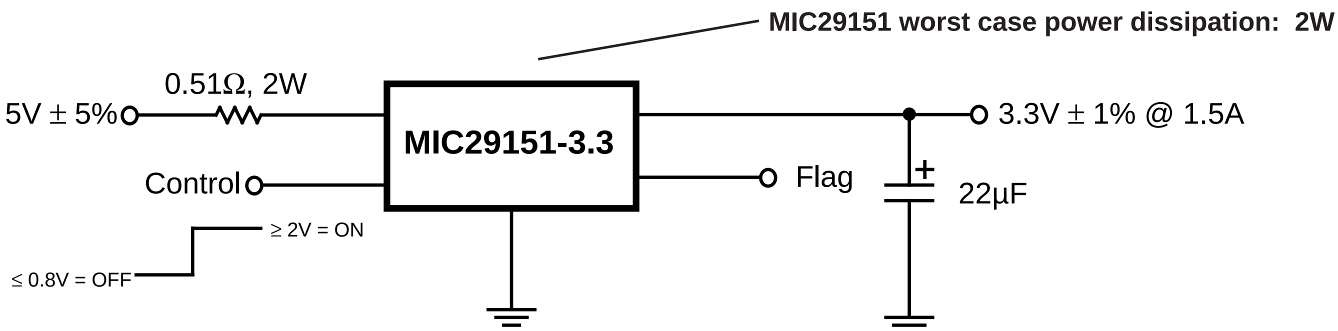

Figure 4. The MIC29151-3.3 produces 1.5A at 3.3V. No heat sink is necessary in most situations when the external power sharing resistor is employed.

Notes

NOTE 1: The MIC29150, MIC29300, MIC29500, and MIC29750 LDO regulator family feature trimmed outputs guaranteed to ±1% under standard conditions. Across the full temperature range, with load and input voltage variations, the device output voltage varies less than 2% worst case.

NOTE 2: The mounting tab of the MIC29150 family regulators is grounded. The estimated value of θ_{CS} assumes no electrical insulation between mounting tab and heat sink.

NOTE 3: AAVID Engineering, Inc., One Kool Path, Laconia, NH 03247. (603) 528-3400.

NOTE 4: Thermalloy Inc., P.O. Box 810839, Dallas, TX 75381. (214) 243-4321.

NOTE 5: Super ßeta PNP™ is a registered trademark of Micrel, Inc.