

LM138QML Military Grade 5-A Adjustable Output Linear Regulator

1 Features

- Manufactured and Tested per Texas Instruments Military Grade Flow
- Specified 7-A Peak Output Current
- Specified 5-A Output Current
- Wide Temperature Range -55°C to 150°C
- Adjustable Output Down to 1.2 V
- Specified Thermal Regulation
- Current Limit Constant With Temperature
- P+ Product Enhancement Tested
- Output is Short-Circuit Protected

2 Applications

- Adjustable Power Supplies
- Constant Current Regulators
- Battery Chargers

3 Description

The LM138QML adjustable 3-terminal positive voltage regulator is capable of supplying in excess of 5 A over a 1.2-V to 32-V output range. The device is exceptionally easy to use and requires only two resistors to set the output voltage. Careful circuit design has resulted in outstanding load and line regulation—comparable to many commercial power supplies.

A unique feature of the LM138QML device is time-dependent current limiting. The current limit circuitry allows peak currents of up to 12 A to be drawn from the regulator for short periods of time. This allows the LM138QML device to be used with heavy transient loads and speeds start-up under full-load conditions. Under sustained loading conditions, the current limit decreases to a safe value protecting the regulator. Also included on the chip are thermal overload protection and safe area protection for the power transistor. Overload protection remains functional even if the adjustment pin is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors, in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

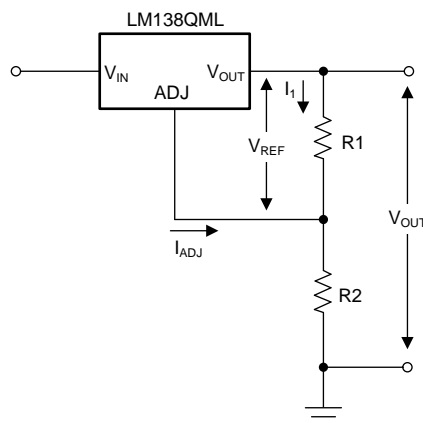
Besides replacing fixed regulators or discrete designs, the LM138QML is useful in a wide variety of other applications. Since the regulator is “floating” and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded; that is, do not short-circuit output to ground.

Device Information⁽¹⁾

PART NUMBER	GRADE	PACKAGE
LM138K-MIL	Military	TO-3 (2)
LM138KG-MD8	Military	Die
LM138KG-MW8	Military	Wafer

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application Circuit



Copyright © 2017, Texas Instruments Incorporated



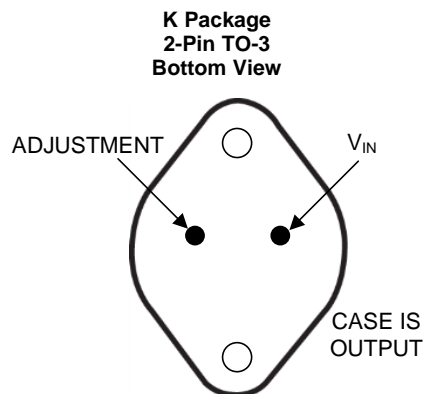
Table of Contents

1 Features	1	7.4 Device Functional Modes.....	11
2 Applications	1	8 Application and Implementation	12
3 Description	1	8.1 Application Information.....	12
4 Revision History	2	8.2 Typical Applications	13
5 Pin Configuration and Functions	3	8.3 System Examples	17
6 Specifications	4	9 Power Supply Recommendations	29
6.1 Absolute Maximum Ratings	4	10 Layout	29
6.2 Recommended Operating Conditions.....	4	10.1 Layout Guidelines	29
6.3 Thermal Information	5	10.2 Layout Example	29
6.4 Electrical Characteristics.....	5	11 Device and Documentation Support	30
6.5 Quality Conformance Inspection	6	11.1 Receiving Notification of Documentation Updates	30
6.6 Typical Performance Characteristics	7	11.2 Community Resources.....	30
7 Detailed Description	10	11.3 Trademarks	30
7.1 Overview	10	11.4 Electrostatic Discharge Caution.....	30
7.2 Functional Block Diagram	10	11.5 Glossary	30
7.3 Feature Description.....	10	12 Mechanical, Packaging, and Orderable Information	30

4 Revision History

DATE	REVISION	NOTES
October 2017	*	Initial release.

5 Pin Configuration and Functions



Package Number K0002C

Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
ADJ	1	I	Output voltage adjustment pin. Connect to a resistor divider to set V_O .
V_{IN}	2	I	Supply input pin.
V_{OUT}	Case	O	Voltage output pin.

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

	MIN	MAX	UNIT
Power dissipation	Internally limited		
Input and output voltage differential	-0.3	40	V
Storage temperature, T_{stg}	-65	150	°C
Lead temperature (soldering, 10 seconds)		300	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.2 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	MAX	UNIT
Operating temperature, T_J	-55	150	°C
Input-to-output voltage differential	3	40	V
Output current		5	A

6.3 Thermal Information

THERMAL METRIC ⁽¹⁾		LM138QML	UNIT
		K (TO-3)	
		2 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	42.8	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	3.3	°C/W
ψ _{JT}	Junction-to-top characterization parameter	2.5	°C/W
ψ _{JB}	Junction-to-board characterization parameter	37.4	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

6.4 Electrical Characteristics

Values apply for V_{IN} – V_{OUT} = 5 V; and I_{OUT} = 10 mA (unless otherwise noted)⁽¹⁾

PARAMETER	TEST CONDITIONS	SUB-GROUPS	MIN	TYP ⁽²⁾	MAX	UNIT
V _{REF} Reference voltage	V _{IN} – V _{OUT} = 3 V ⁽³⁾	[1, 2, 3]	1.19		1.29	V
	V _{IN} – V _{OUT} = 3 V, I _{OUT} = 5 A	[1, 2, 3]	1.19		1.29	
	V _{IN} – V _{OUT} = 5 V, I _{OUT} = 7 A	[1, 2, 3]	1.19		1.29	
	V _{IN} – V _{OUT} = 35 V	[1, 2, 3]	1.19		1.29	
	V _{IN} – V _{OUT} = 35 V, I _{OUT} = 150 mA	[1, 2, 3]	1.19		1.29	
V _{RLINE} Line regulation ⁽⁴⁾	3 V ≤ (V _{IN} – V _{OUT}) ≤ 35 V	[1]	–3.5		3.5	mV
	3.3 V ≤ (V _{IN} – V _{OUT}) ≤ 35 V	[2, 3]	–14		14	
V _{RLOAD} Load regulation ⁽⁴⁾	V _{IN} – V _{OUT} = 3 V, 10 mA ≤ I _{OUT} ≤ 5 A, V _{OUT} = V _{REF}	[1]	–3.8		3.8	mV
	V _{IN} – V _{OUT} = 3.3 V, 10 mA ≤ I _{OUT} ≤ 5 A, V _{OUT} = V _{REF}	[2, 3]	–8		8	
	V _{IN} – V _{OUT} = 35 V, 10 mA ≤ I _{OUT} ≤ 150 mA, V _{OUT} = V _{REF}	[1] [2, 3]	–3.8 –8		3.8 8	
V _{RTH} Thermal regulation	V _{IN} – V _{OUT} = 10 V, pulse = 20 ms, I _{OUT} = 1 A ⁽⁵⁾	[1]		0.002	0.01	%/W
I _{ADJ} Adjustment pin current	V _{IN} – V _{OUT} = 3 V ⁽³⁾	[1, 2, 3]	2	45	100	μA
	V _{IN} – V _{OUT} = 35 V	[1, 2, 3]	2		100	
ΔI _{ADJ} Adjustment pin current change	3 V ≤ (V _{IN} – V _{OUT}) ≤ 35 V ⁽³⁾	[1, 2, 3]	–5	0.2	5	μA
	10 mA ≤ I _{OUT} ≤ 5 A	[1, 2, 3]	–5		5	
I _{LOAD(MIN)} Minimum load current	V _{IN} – V _{OUT} = 3 V, V _{OUT} = 1.4 V ⁽³⁾	[1, 2, 3]	0.5		5	mA
	V _{IN} – V _{OUT} = 35 V, V _{OUT} = 1.4 V	[1, 2, 3]	0.5	3.5	5	
I _{CL} Current limit	V _{IN} – V _{OUT} = 10 V, T = 0.5 ms, V _{OUT} = 0 V	[1, 2, 3]	7		16	A
	T = 5 ms, V _{OUT} = 0 V	[1, 2, 3]	5		15	
ΔV _R /ΔV _{IN} Ripple rejection ratio	V _{OUT} = V _{REF} , e _{IN} = 1 V _{RMS} , f = 120 Hz, I _{OUT} = 500 mA ⁽⁶⁾	[4]	60			dB

- (1) These specifications are applicable for power dissipations up to 50W. Power dissipation is specified at these values up to 15-V input-output differential. Above 15-V differential, power dissipation will be limited by internal protection circuitry. All limits (that is, the numbers in the minimum and maximum columns) are specified to TI's AOQL (Average Outgoing Quality Level).
- (2) Typical figures are at T_A = 25°C, and represent most likely parametric norms. Test limits are ensured to Texas Instruments' average outgoing quality level (AOQL).
- (3) V_{IN} – V_{OUT} = 3.3 V at –55°C and 125°C.
- (4) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.
- (5) Datalog reading in mV, 0.01% = 1.19 mV.
- (6) Family board not required for this device.

6.5 Quality Conformance Inspection

MIL-STD-883, Method 5005 - Group A

SUBGROUP	DESCRIPTION	TEMPERATURE (°C)
1	Static tests at	25
2	Static tests at	125
3	Static tests at	-55
4	Dynamic tests at	25
5	Dynamic tests at	125
6	Dynamic tests at	-55
7	Functional tests at	25
8A	Functional tests at	125
8B	Functional tests at	-55
9	Switching tests at	25
10	Switching tests at	125
11	Switching tests at	-55
12	Setting time at	25
13	Setting time at	125
14	Setting time at	-55

6.6 Typical Performance Characteristics

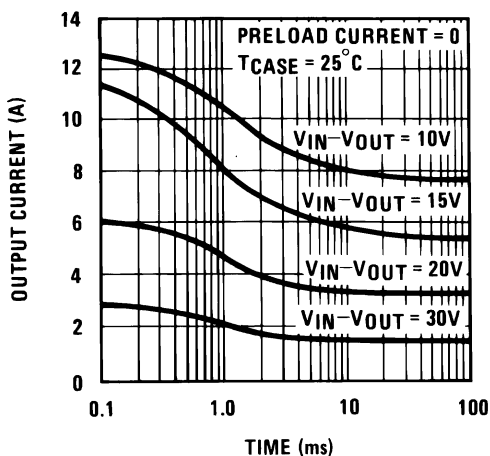


Figure 1. Current Limit

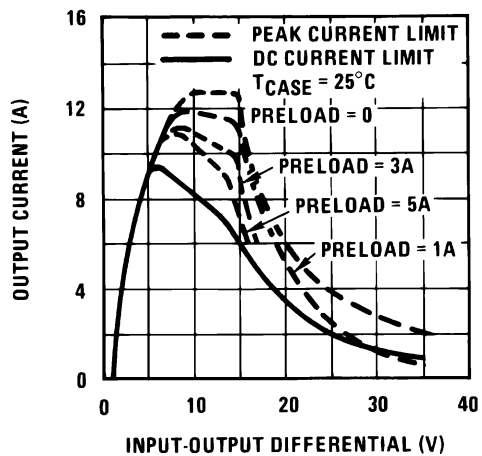


Figure 2. Current Limit

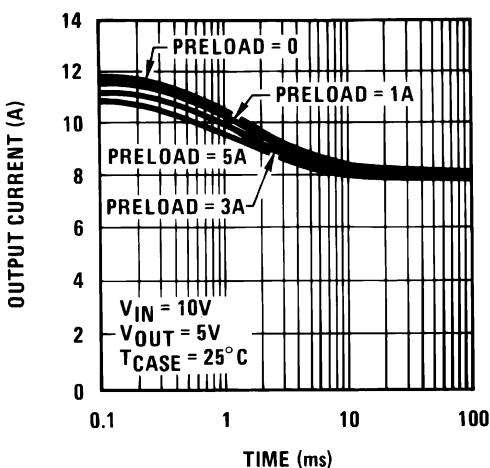


Figure 3. Current Limit

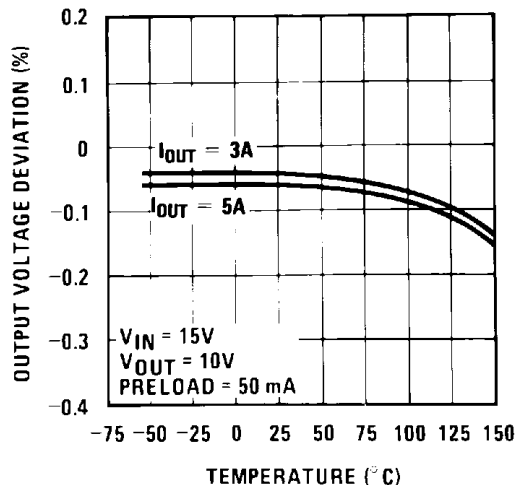


Figure 4. Load Regulation

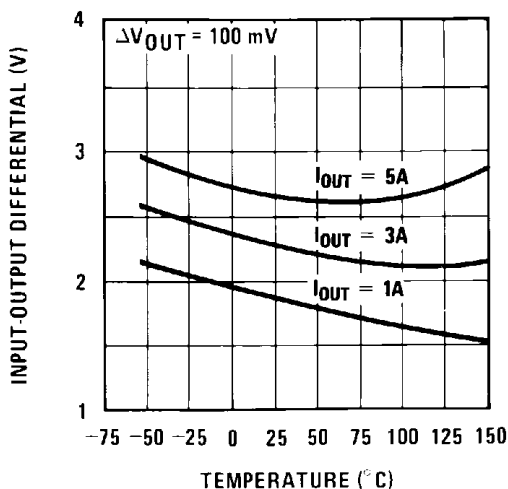


Figure 5. Dropout Voltage

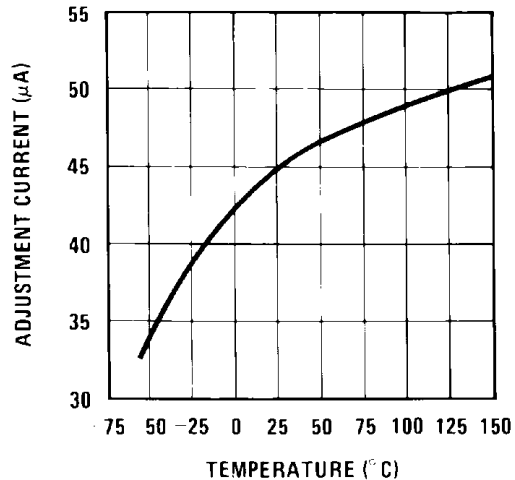
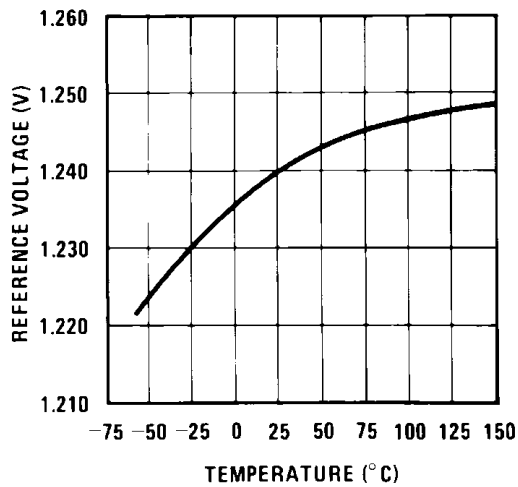
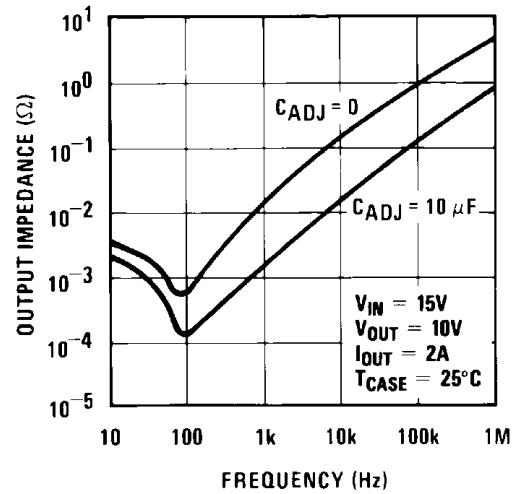
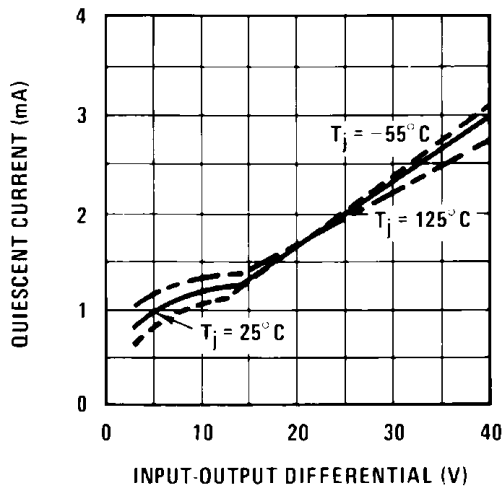
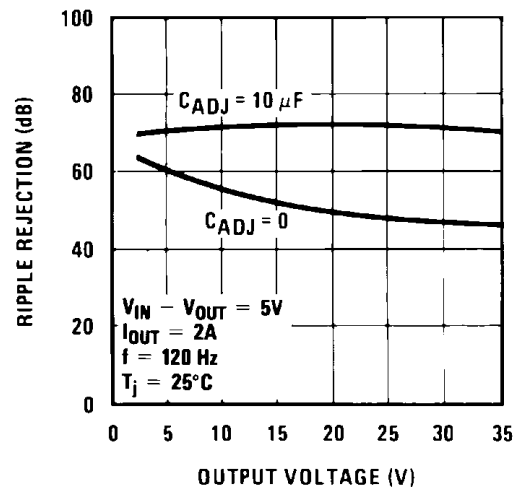
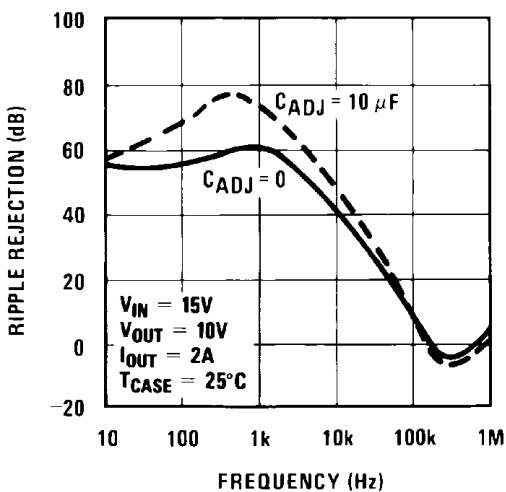
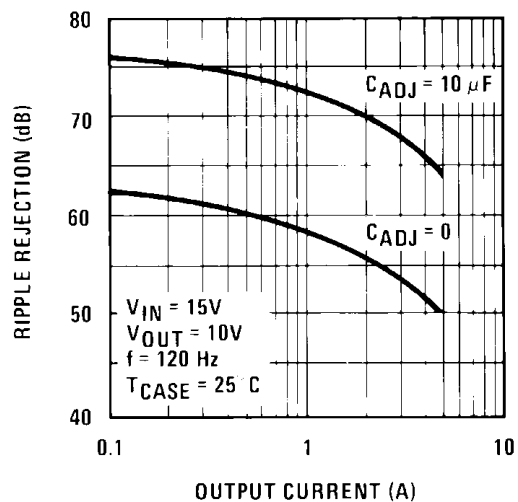
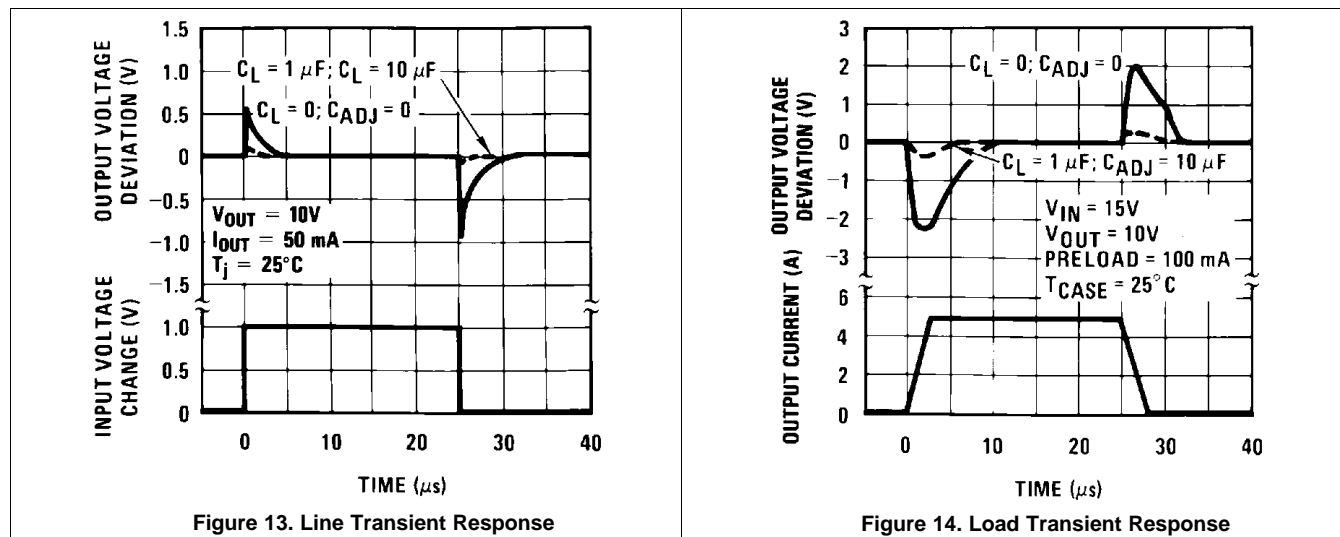


Figure 6. Adjustment Current

Typical Performance Characteristics (continued)

Figure 7. Temperature Stability

Figure 8. Output Impedance

Figure 9. Minimum Operating Current

Figure 10. Ripple Rejection

Figure 11. Ripple Rejection

Figure 12. Ripple Rejection

Typical Performance Characteristics (continued)



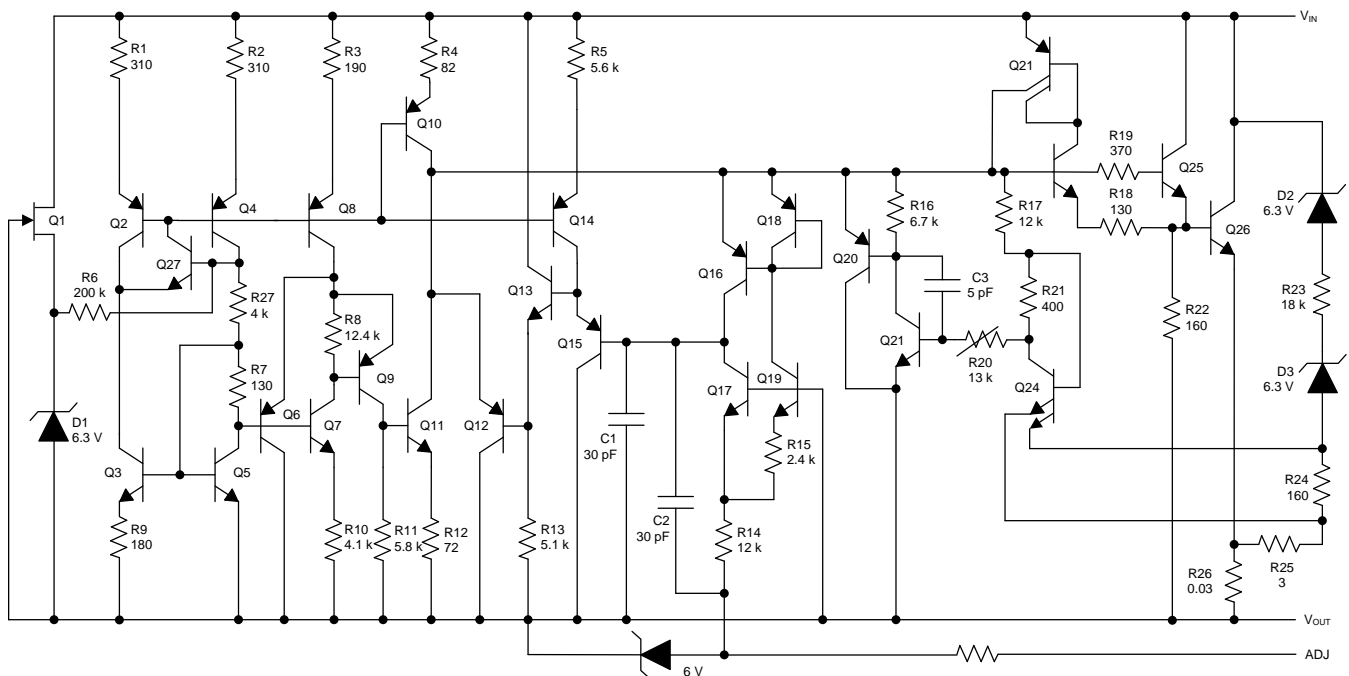
7 Detailed Description

7.1 Overview

The LM138QML device is an adjustable, three-terminal, positive-voltage regulator capable of supplying more than 5 A over an output-voltage range of 1.2 V to 32 V. It requires only two external resistors to set the output voltage. The LM138QML device features a typical line regulation of 0.005% and typical load regulation of 0.1%. It includes time-dependent current limiting, thermal overload protection, and safe operating area protection. Overload protection remains functional even if the ADJUST terminal is disconnected.

The LM138QML devices are versatile in their applications, including uses in programmable output regulation and local on-card regulation. Or, by connecting a fixed resistor between the ADJUST and OUTPUT terminals, the LM138QML device can function as a precision current regulator. An optional output capacitor can be added to improve transient response. The ADJUST terminal can be bypassed to achieve very high ripple-rejection ratios, which are difficult to achieve with standard three-terminal regulators.

7.2 Functional Block Diagram



Copyright © 2017, Texas Instruments Incorporated

7.3 Feature Description

7.3.1 NPN Darlington Output Drive

NPN Darlington output topology provides naturally low output impedance and an output capacitor is optional. To support maximum current and lowest temperature, 3-V headroom is recommended ($V_I - V_O$).

7.3.2 Overload Block

Overcurrent and overtemperature shutdown protects the device against overload or damage from operating in excessive heat.

7.3.3 Programmable Feedback

An op amp with 1.25-V offset input at the ADJUST terminal provides easy output voltage or current, but not both, programming. For current regulation applications, a single resistor whose resistance value is $1.25 V/I_O$ and power rating is greater than $1.25 V^2/R$ must be used. For voltage regulation applications, two resistors set the output voltage.

7.4 Device Functional Modes

7.4.1 Normal Operation

The device OUTPUT pin sources current necessary to make the OUTPUT pin 1.25-V greater than the ADJUST terminal to provide output regulation.

7.4.2 Operation With Low Input Voltage

The device requires up to 3-V headroom ($V_I - V_O$) to operate in regulation. With less headroom, the device may drop out and the OUTPUT voltage is then the INPUT voltage minus the drop out voltage.

7.4.3 Operation at Light Loads

The device passes its bias current to the OUTPUT pin. The load or feedback must consume this minimum current for regulation or the output may be too high. A 250- Ω feedback resistor between OUTPUT and ADJUST consumes the worst case minimum load current of 5 mA.

7.4.4 Operation in Self Protection

When an overload occurs, the device shuts down the Darlington NPN output stage or reduces the output current to prevent device damage. The device automatically resets from the overload. The output may be reduced or alternate between on and off until the overload is removed.

8 Application and Implementation

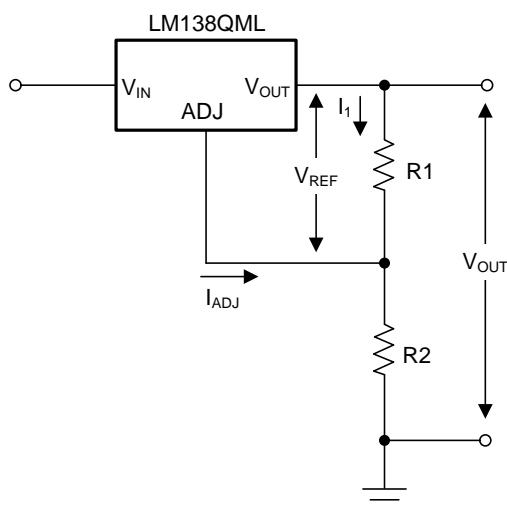
NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

In operation, the LM138QML device develops a nominal 1.25-V reference voltage, V_{REF} , between the output and adjustment terminal. The reference voltage is impressed across program resistor R_1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R_2 , giving an output voltage of:

$$V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ} R_2 \quad (1)$$

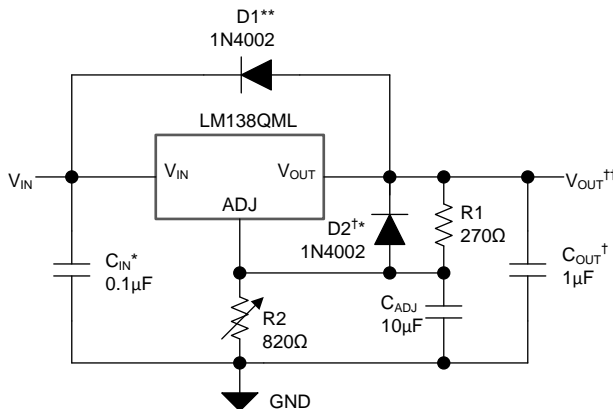


Copyright © 2017, Texas Instruments Incorporated

Because the 50- μ A current from the adjustment terminal represents an error term, the LM138QML was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output rises.

8.2 Typical Applications

8.2.1 Constant 5-V Regulator



*Needed if device is more than 6 inches from filter capacitors

†Optional—improves transient response

**Recommended if C_{OUT} is used

$$\ddagger V_{OUT} = 1.25V \left(1 + \frac{R2}{R1} \right) + I_{ADJ} (R2)$$

†*Recommended if C_{ADJ} is used

Copyright © 2017, Texas Instruments Incorporated

Figure 15. Constant 5-V Regulator

8.2.1.1 Design Requirements

Table 1. Design Parameters

PARAMETER	PART NUMBER/VALUE	DESCRIPTION
Feedback resistor 1 (R1)	270 Ω	The LM138QML produces a typical 1.24-V potential between the OUTPUT and ADJUST pins; therefore, placing a 270-Ω resistor between the OUTPUT and ADJUST pins causes 4.6 mA to flow through R1 and R2
Feedback resistor 2 (R2)	820 Ω	To achieve a 5-V output, the sum of the voltages across R1 and R2 must equal 5 V. Therefore, V _{R2} must equal 3.76 V when 4.6 mA is flowing through it. R2 = V _{R2} / I = 3.76 V / 4.6 mA = ~820 Ω.
Input capacitor (C _{IN})	0.1 µF	0.1 µF of input capacitance helps filter out unwanted noise, especially if the regulator is located far from the power supply filter capacitors.
Output capacitor (C _{OUT})	1 µF	The regulator is stable without any output capacitance, but adding a 1-µF capacitor improves the transient response.
Adjust capacitor (C _{ADJ})	10 µF	A 10-µF capacitor bypassing the ADJUST pin to ground improves the regulators ripple rejection.
Protection diode 1 (D1)	1N4002	Protection diode D1 is recommended if C _{OUT} is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator (see Protection Diodes).
Protection diode 2 (D2)	1N4002	Protection diode D2 is recommended if C _{ADJ} is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator (see Protection Diodes).

8.2.1.2 Detailed Design Procedure

8.2.1.2.1 External Capacitors

An input bypass capacitor is recommended. A 0.1- μF disc or 1- μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM138QML to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10- μF bypass capacitor, 75-dB ripple rejection is obtainable at any output level. Increases over 20 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

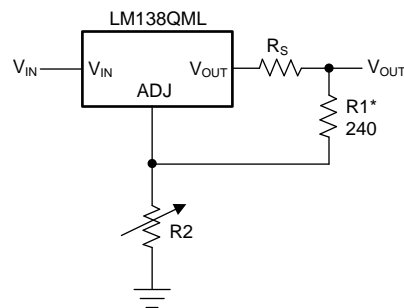
In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1- μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; however, some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, a 0.01- μF disc may seem to work better than a 0.1- μF disc as a bypass.

Although the LM138QML is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1- μF solid tantalum (or 25- μF aluminum electrolytic) on the output swamps this effect and insures stability.

8.2.1.2.2 Load Regulation

The LM138QML device is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240 Ω) should be tied directly to the output of the regulator (case) rather than near the load; this eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15-V regulator with 0.05- Ω resistance between the regulator and load will have a load regulation due to line resistance of $0.05 \Omega \times I_L$. If the set resistor is connected near the load the effective line resistance will be $0.05 \Omega (1 + R_2/R_1)$ or in this case, 11.5 times worse.

Figure 16 shows the effect of resistance between the regulator and 240- Ω set resistor.



Copyright © 2017, Texas Instruments Incorporated

Figure 16. Regulator With Line Resistance in Output Lead

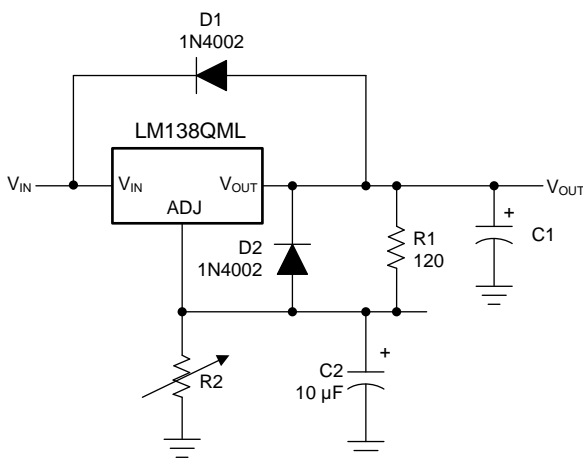
With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor by using two separate leads to the case. The ground of R₂ can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

8.2.1.2.3 Protection Diodes

When external capacitors are used with *any* IC regulator, it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20- μF capacitors have low enough internal series resistance to deliver 20-A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor discharges into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN} . In the LM138QML, this discharge path is through a large junction that is able to sustain 25-A surge with no problem; this is not true of other types of positive regulators. For output capacitors of 100 μF or less at an output of 15 V or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM138QML is a 50- Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25-V or less and 10- μF capacitance. **Figure 17** shows an LM138QML with protection diodes included for use with outputs greater than 25 V and high values of output capacitance.



Copyright © 2017, Texas Instruments Incorporated

D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25 \text{ V} \left(1 + \frac{R2}{R1} \right) + I_{ADJ} R2$$

Figure 17. Regulator With Protection Diodes

8.2.1.3 Application Curves

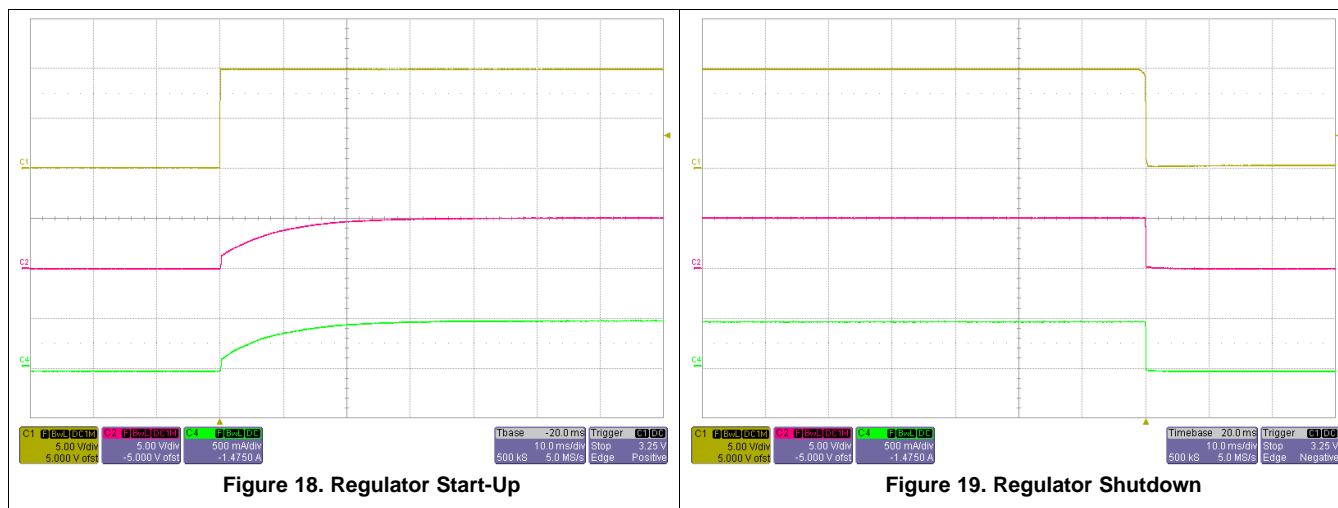
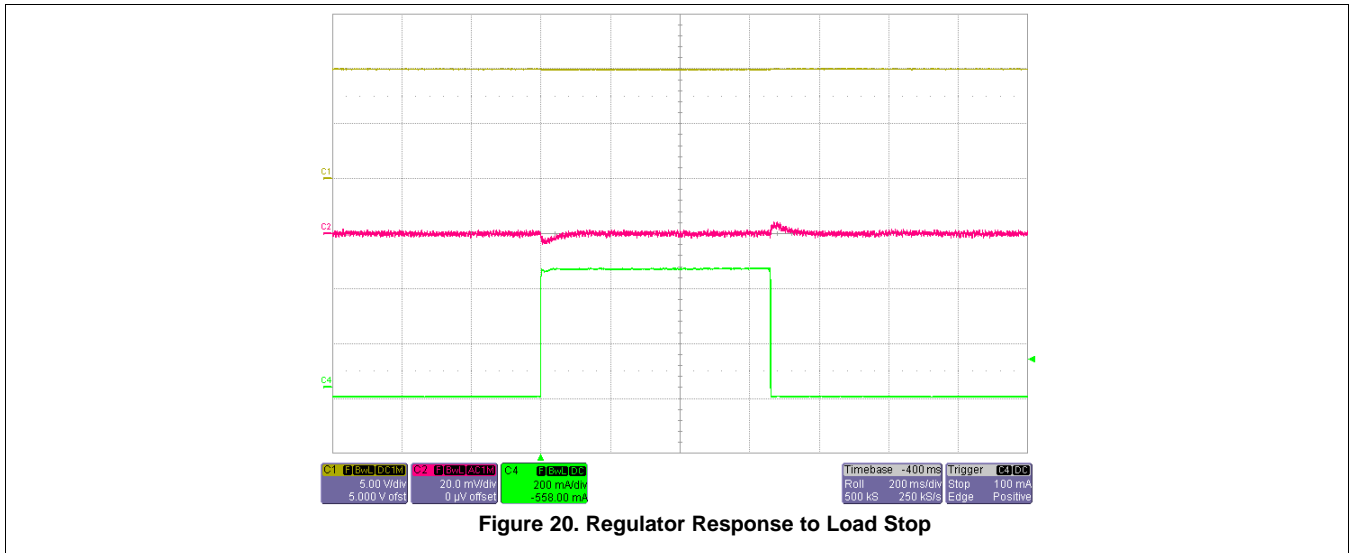
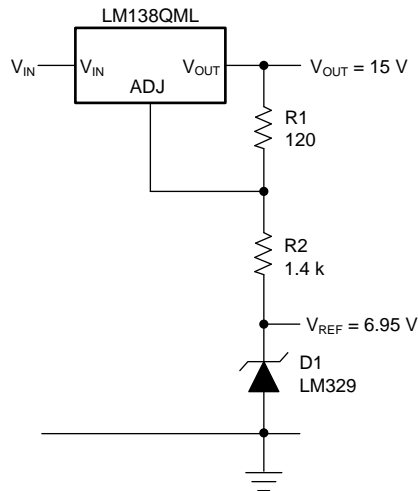


Figure 18. Regulator Start-Up

Figure 19. Regulator Shutdown

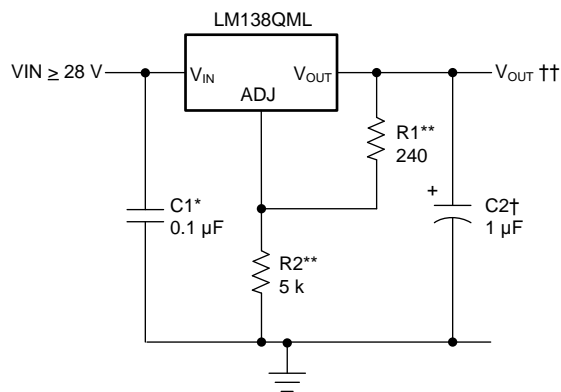


8.3 System Examples



Copyright © 2017, Texas Instruments Incorporated

Figure 21. Regulator and Voltage Reference



Copyright © 2017, Texas Instruments Incorporated

Full output current not available at high input-output voltages

† Optional—improves transient response. Output capacitors in the range of 1 μ F to 1000 μ F of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

* Needed if device is more than 6 inches from filter capacitors.

$$\dagger\dagger V_{OUT} = 1.25 \text{ V} \left(1 + \frac{R_2}{R_1} \right) + I_{ADJ}(R_2)$$

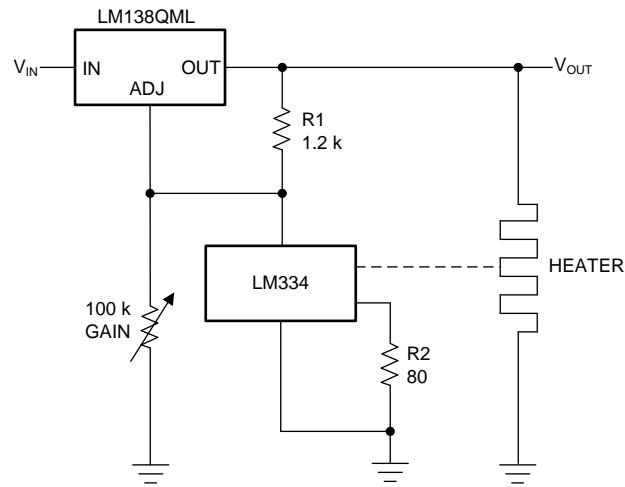
** R1, R2 as an assembly can be ordered from Bourns:

MIL part no. 7105A-AT2-502

COMM part no. 7105A-AT7-502

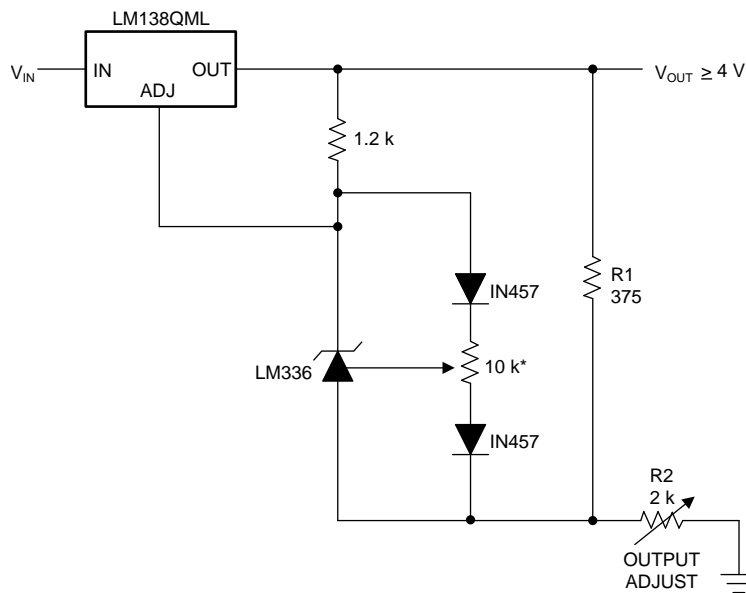
Figure 22. 1.2-V to 25-V Adjustable Regulator

System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

Figure 23. Temperature Controller

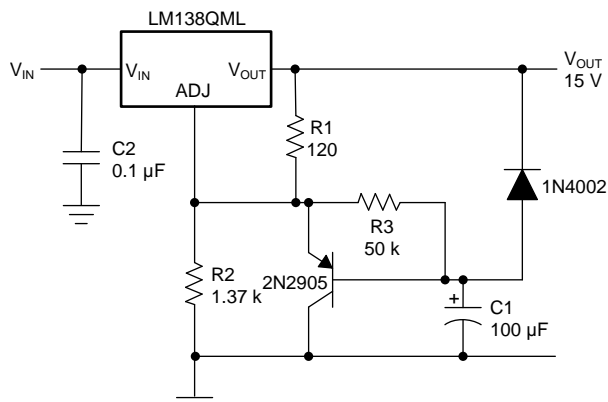


Copyright © 2017, Texas Instruments Incorporated

* Adjust for 3.75 V across R1

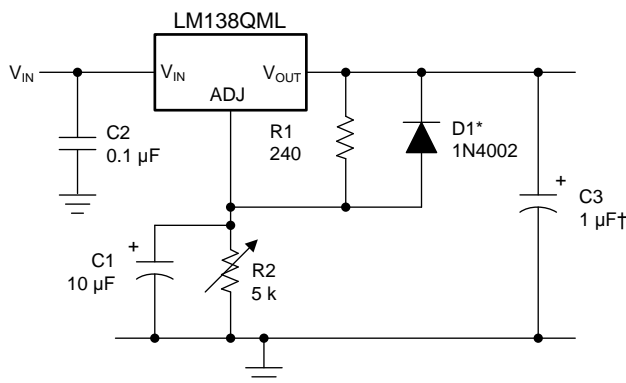
Figure 24. Precision Power Regulator With Low Temperature Coefficient

System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

Figure 25. Slow Turnon 15-V Regulator

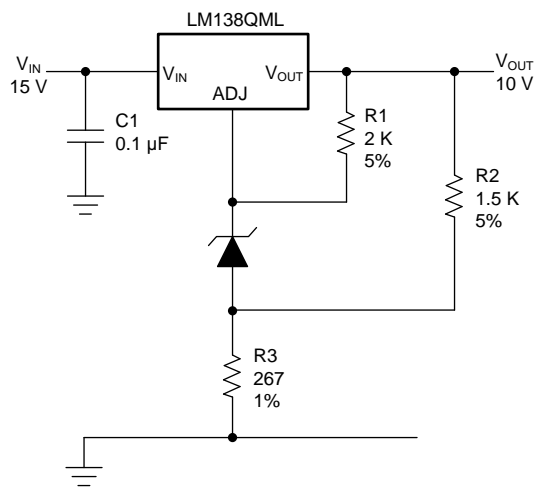


Copyright © 2017, Texas Instruments Incorporated

† Solid tantalum

* Discharges C1 if output is shorted to ground

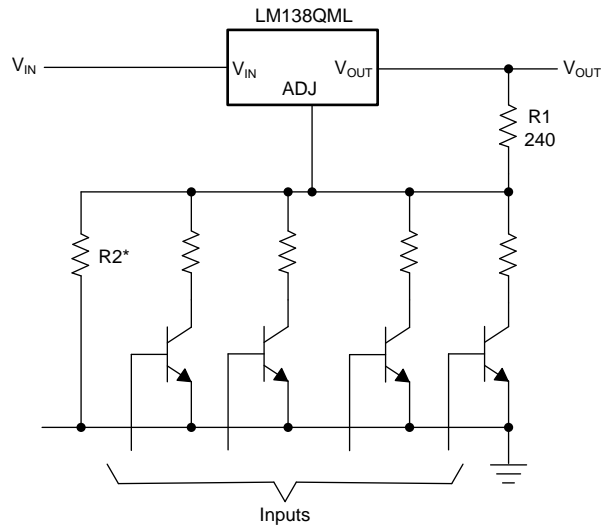
Figure 26. Adjustable Regulator With Improved Ripple Rejection



Copyright © 2017, Texas Instruments Incorporated

Figure 27. High Stability 10-V Regulator

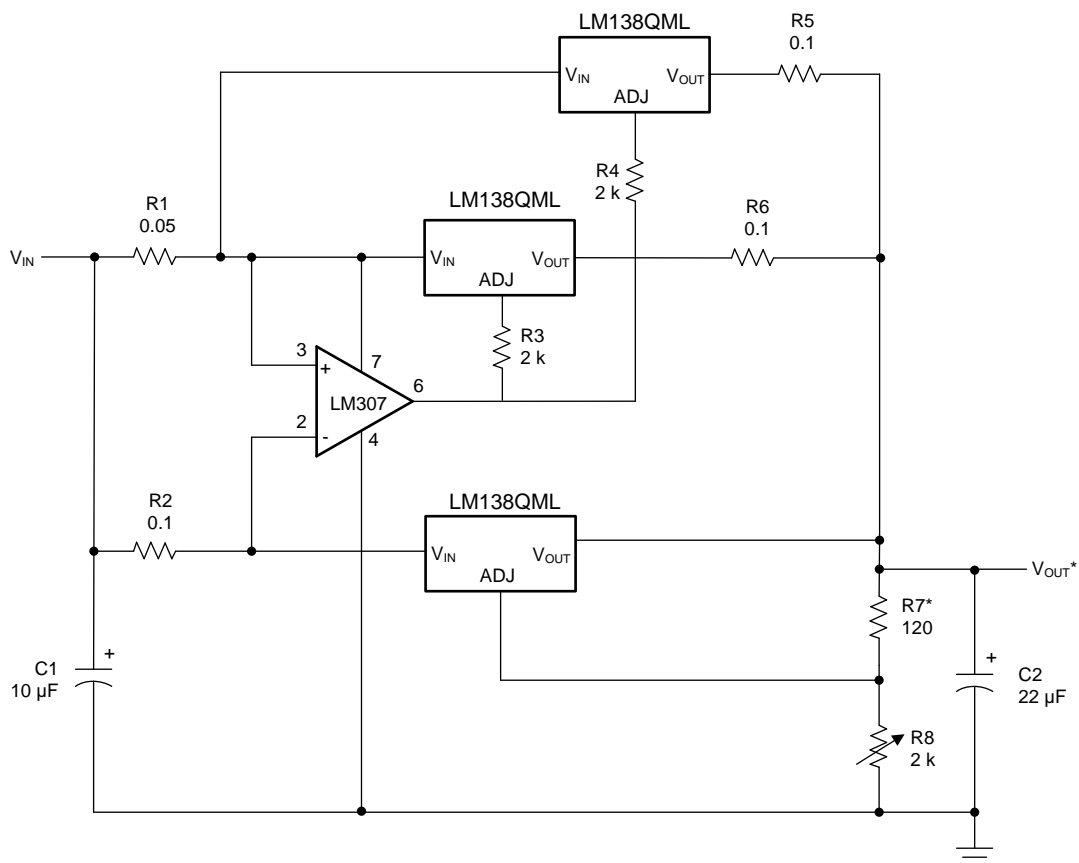
System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

* Sets maximum V_{OUT}

Figure 28. Digitally Selected Outputs

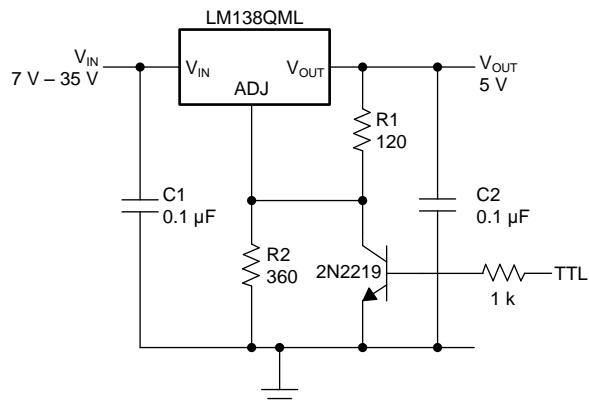


Copyright © 2017, Texas Instruments Incorporated

* Minimum load—100 mA

Figure 29. 15-A Regulator

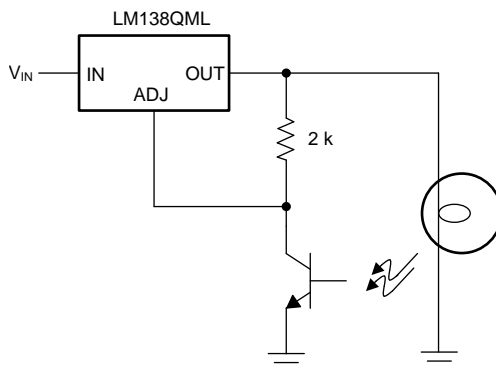
System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

** Minimum output \approx 1.2 V

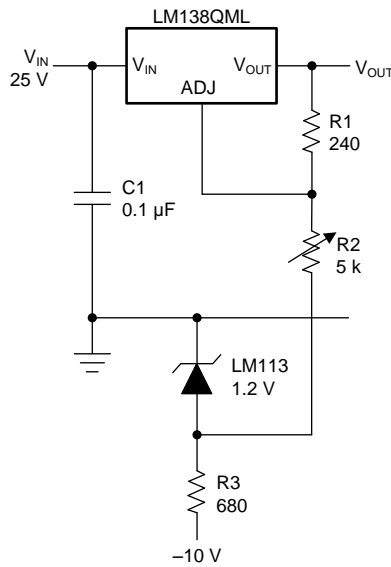
Figure 30. 5-V Logic Regulator With Electronic Shutdown**



Copyright © 2017, Texas Instruments Incorporated

Figure 31. Light Controller

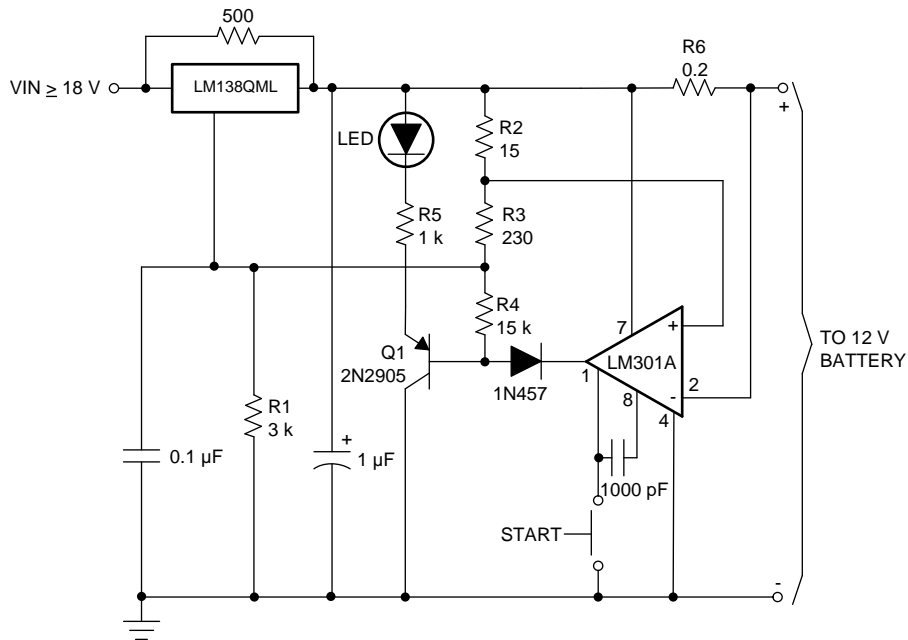
System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

Full output current not available at high input-output voltages

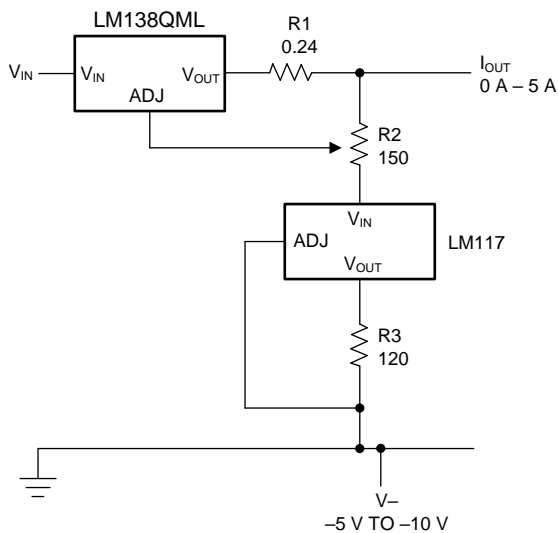
Figure 32. 0-V to 22-V Regulator



Copyright © 2017, Texas Instruments Incorporated

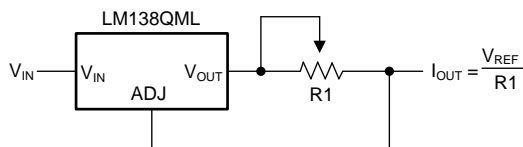
Figure 33. 12-V Battery Charger

System Examples (continued)



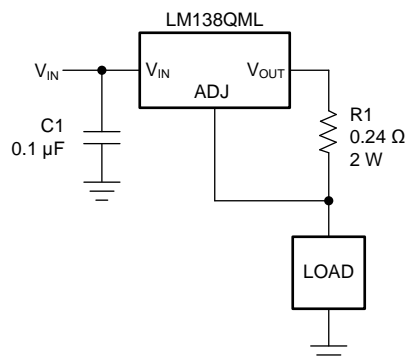
Copyright © 2017, Texas Instruments Incorporated

Figure 34. Adjustable Current Regulator



Copyright © 2017, Texas Instruments Incorporated

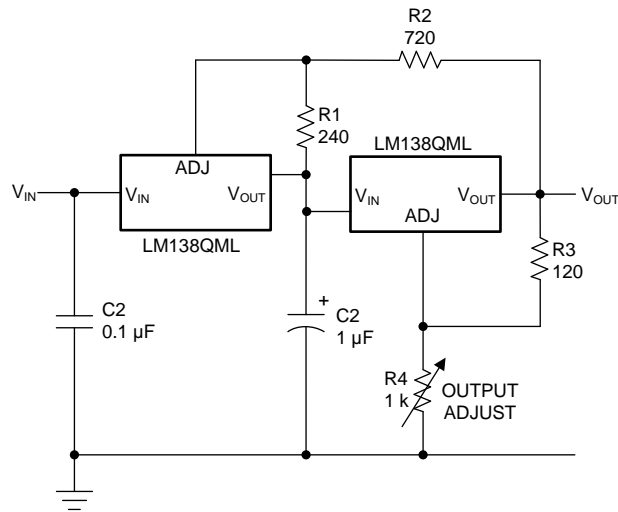
Figure 35. Precision Current Limiter



Copyright © 2017, Texas Instruments Incorporated

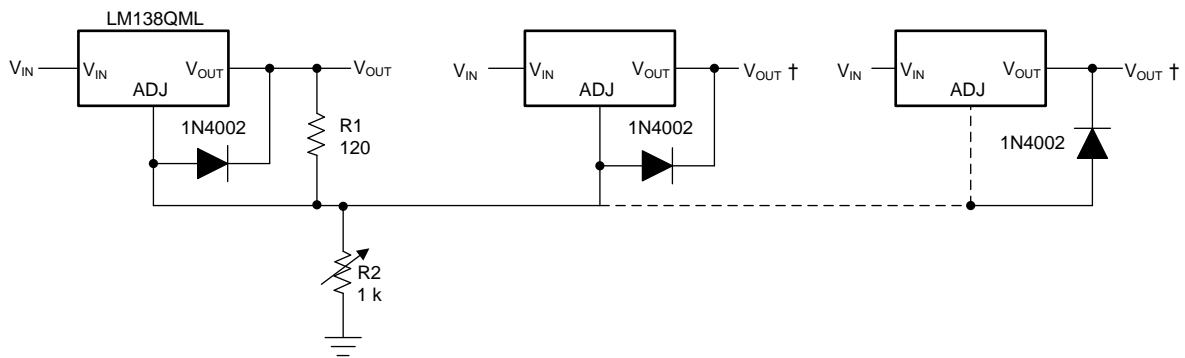
Figure 36. 5-A Current Regulator

System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

Figure 37. Tracking Preregulator

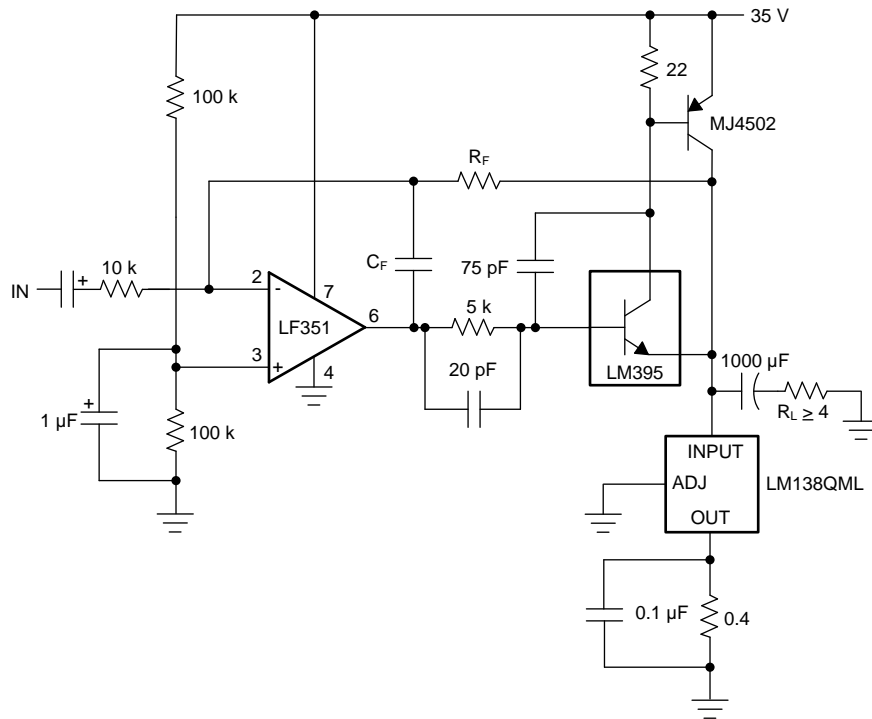


Copyright © 2017, Texas Instruments Incorporated

† Minimum load—10 mA
 * All outputs within ±100 mV

Figure 38. Adjusting Multiple On-Card Regulators With Single Control*

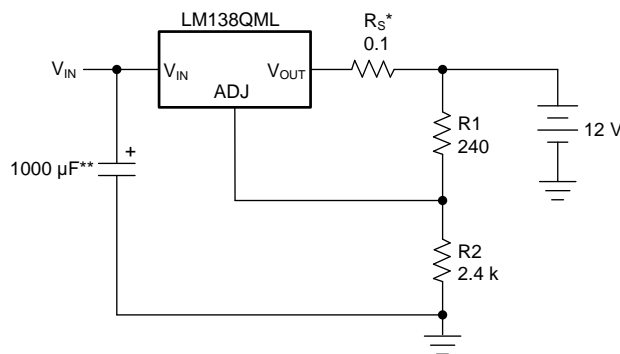
System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

$A_V = 1$, $R_F = 10k$, $C_F = 100$ pF
 $A_V = 10$, $R_F = 100k$, $C_F = 10$ pF
 Bandwidth ≥ 100 kHz
 Distortion $\leq 0.1\%$

Figure 39. Power Amplifier

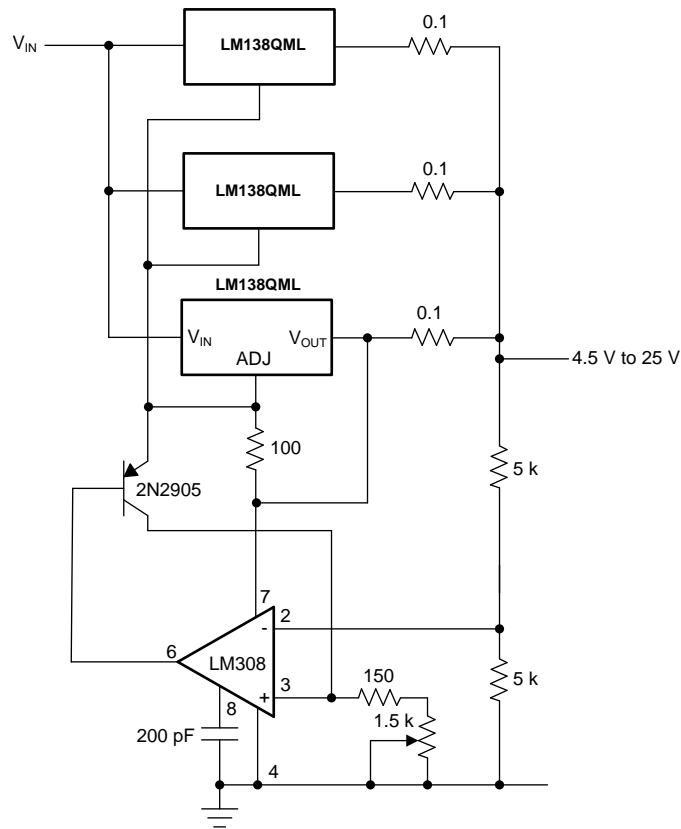


Copyright © 2017, Texas Instruments Incorporated

$Z_{OUT} = R_S \left(1 + \frac{R_2}{R_1} \right)$
 * R_S sets output impedance of charger
 Use of R_S allows low charging rates with fully charged battery.
 ** The 1000 μ F is recommended to filter out input transients

Figure 40. Simple 12-V Battery Charger

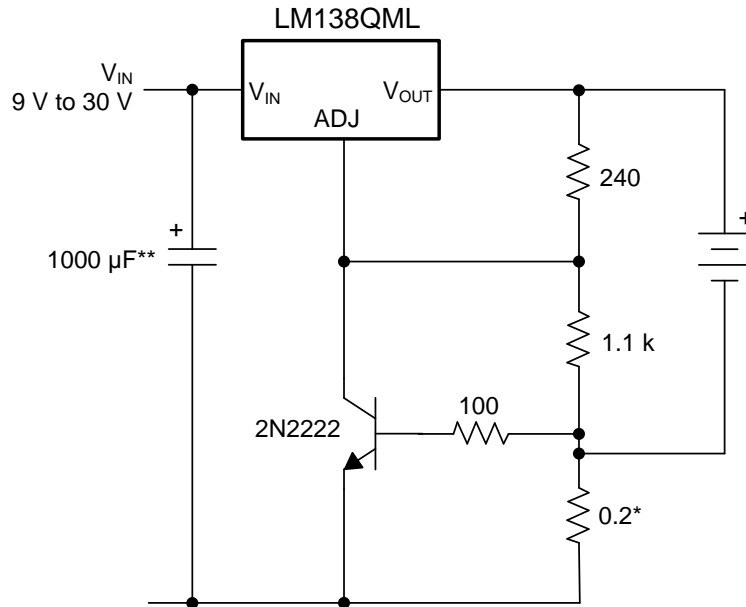
System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

Figure 41. Adjustable 15-A Regulator

System Examples (continued)



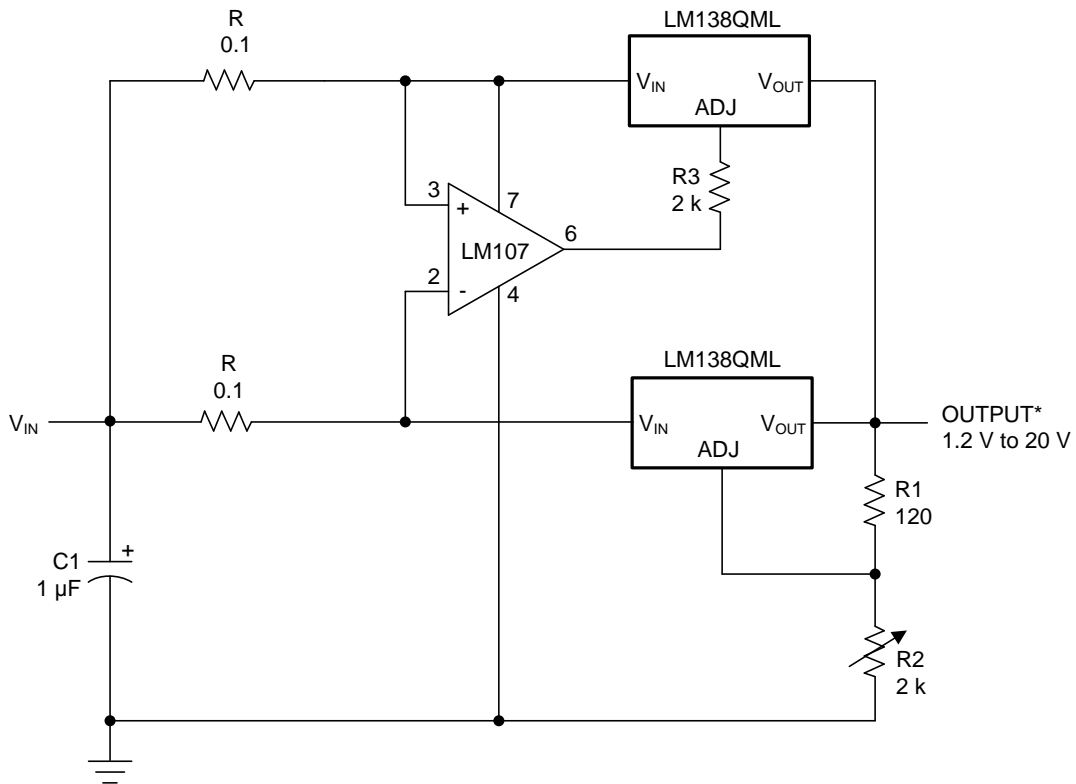
Copyright © 2017, Texas Instruments Incorporated

* Set max charge current to 3 A

** The 1000 µF is recommended to filter out input transients.

Figure 42. Current Limited 6-V Charger

System Examples (continued)



Copyright © 2017, Texas Instruments Incorporated

* Minimum load—100 mA

Figure 43. 10-A Regulator

9 Power Supply Recommendations

The input supply to LM138QML must be kept at a voltage level such that its maximum input to output differential voltage rating is not exceeded. The minimum dropout voltage must also be met with extra headroom when possible to keep the LM138QML in regulation. TI recommends a capacitor be placed at the input to bypass noise.

10 Layout

10.1 Layout Guidelines

Some layout guidelines must be followed to ensure proper regulation of the output voltage with minimum noise. Traces carrying the load current must be wide to reduce the amount of parasitic trace inductance and the feedback loop from V_{OUT} to ADJ must be kept as short as possible. To improve PSRR, a bypass capacitor can be placed at the ADJ pin and must be placed as close as possible to the device. In cases when V_{IN} shorts to ground, an external diode must be placed from V_{OUT} to V_{IN} to divert the surge current from the output capacitor and protect the device. Similarly, in cases when a large bypass capacitor is placed at the ADJ pin and V_{OUT} shorts to ground, an external diode must be placed from ADJ to V_{OUT} to provide a path for the bypass capacitor to discharge. These diodes must be placed close to the corresponding device pins to increase their effectiveness.

10.2 Layout Example

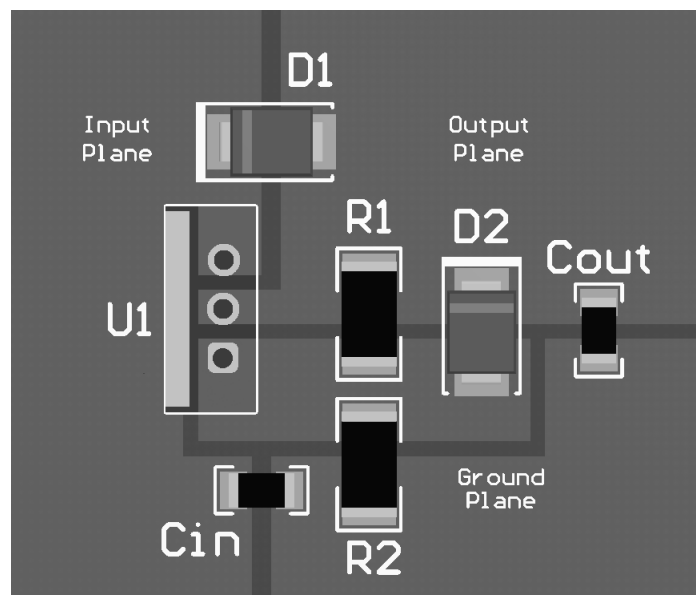


Figure 44. LM138QML Layout

11 Device and Documentation Support

11.1 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.3 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.4 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.5 Glossary

[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM138K-MIL	ACTIVE	TO	K	2	50	Non-RoHS & Non-Green	Call TI	Call TI		LM138K-MIL ACO >T	Samples
LM138KG-MD8	ACTIVE	DIESALE	Y	0	100	RoHS & Green	Call TI	Level-1-NA-UNLIM	-55 to 125		Samples

(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.

NRND: 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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

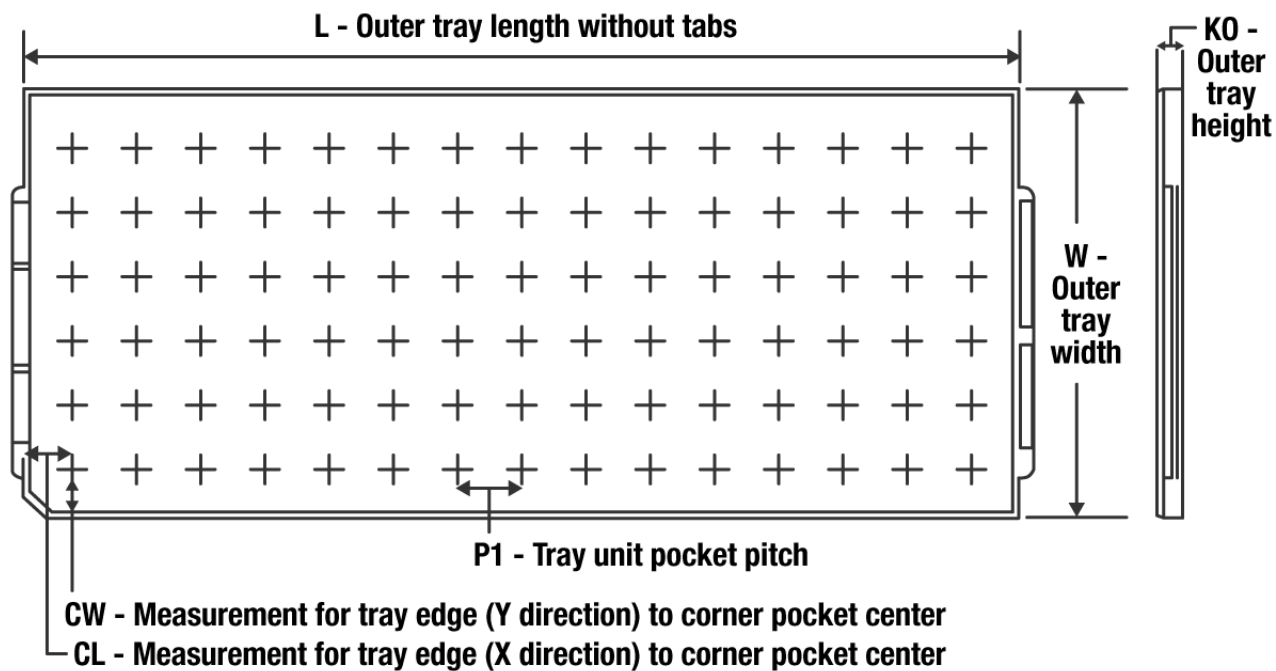
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

Important Information and Disclaimer:The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TRAY


Chamfer on Tray corner indicates Pin 1 orientation of packed units.

*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	Unit array matrix	Max temperature (°C)	L (mm)	W (mm)	K0 (µm)	P1 (mm)	CL (mm)	CW (mm)
LM138K-MIL	K	TO-CAN	2	50	9 X 6	NA	292.1	215.9	25654	3.87	22.3	25.4

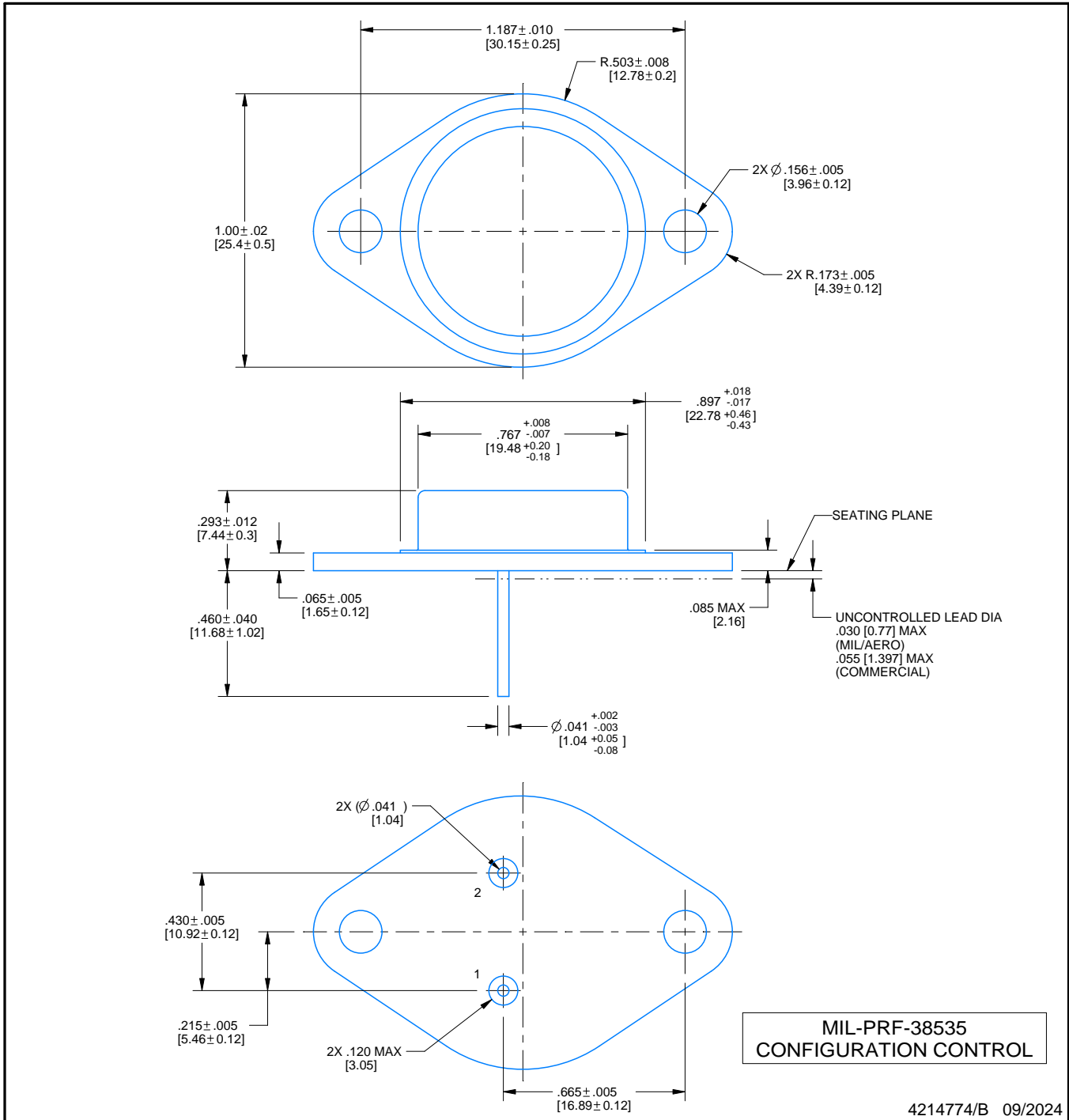
K0002A



PACKAGE OUTLINE

TO-CAN - 7.747 mm max height

TRANSISTOR OUTLINE



NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Leads not to be bent greater than 15°.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2024, Texas Instruments Incorporated