# CS5210-1

# 10A LDO 3-Pin Adjustable Linear Regulator

## Description

The CS5210-1 linear regulator provides 10A at adjustable voltages from 1.25V to 4.5V. This adjustable device requires two external resistors to set the output voltage and provide the minimum load current for proper regulation.

This regulator is intended for use as a post regulator and microprocessor supply. The fast loop response and low dropout voltage make this regulator ideal for applications where low voltage operation and good transient response are important.

The circuit is designed to operate with dropout voltages as low as 1.05V at 10A.

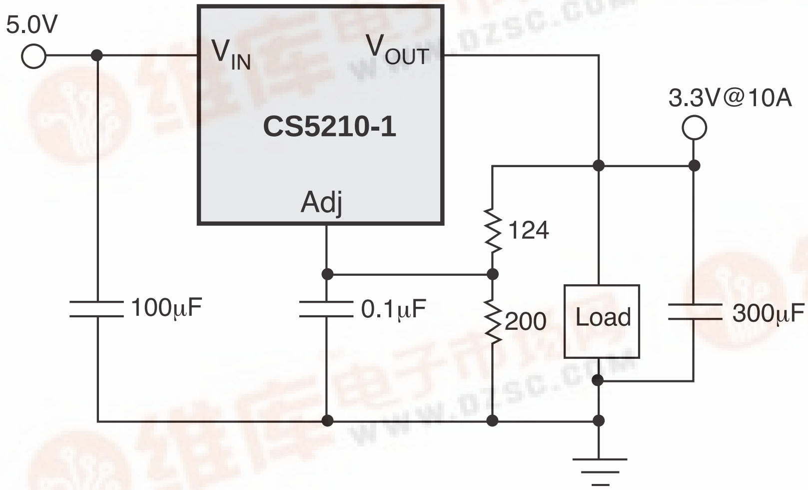
The regulator is protected against overload conditions with overcurrent and thermal shutdown protection circuitry.

The regulator is available in a TO-220 package.

## Features

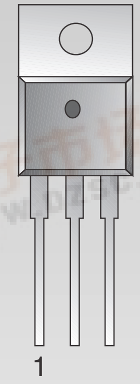
- ☐ 1.25V to 4.5V $V_{OUT}$ at 10A
- ☐ Dropout Voltage < 1.05V @ 10A
- ☐ 2% Trimmed Reference
- ☐ Fast Transient Response
- ☐ Thermal Shutdown
- ☐ Current Limit
- ☐ Short Circuit Protection

### Applications Diagram



## Package Options

### 3 Lead TO-220



1. Adjust
2. $V_{OUT}$
3. $V_{IN}$

Tab = $V_{OUT}$

**Cherry Semiconductor**

Cherry Semiconductor Corporation
2000 South County Trail, East Greenwich, RI 02818
Tel: (401)885-3600 Fax: (401)885-5786
Email: info@cherry-semi.com
Web Site: www.cherry-semi.com

## Absolute Maximum Ratings

Input Voltage ....................................................................................6V
Operating Ambient Temperature Range ....................................................................................0°C ≤ $T_A$ ≤ 70°C
Operating Junction Temperature Range ....................................................................................0°C ≤ $T_J$ ≤ 150°C
Storage Temperature Range ....................................................................................-65°C to +150°C
Lead Temperature Soldering
    Wave Solder (through hole styles only) ....................................................................................10 sec. max, 260°C peak
ESD Damage Threshold ....................................................................................2kV

## Electrical Characteristics: 0°C≤$T_A$ ≤ 70°C, 0°C≤$T_J$ ≤ 150°C, $V_{Adj}$ = 0V unless otherwise specified.

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| Reference voltage | $V_{IN}$=2.75V to 5.5V, $I_{OUT}$=10mA to 10A | 1.227<br>(-2%) | 1.253 | 1.278<br>(+2%) | V |
| Line Regulation | $V_{IN}$=2.75V to 5.5V, $I_{OUT}$=10mA | | .02 | .20 | % |
| Load Regulation | $V_{IN}$=2.75V,$I_{OUT}$=10mA to 10A | | .04 | .50 | % |
| Minimum Load Current (Note 1) | $V_{IN}$=5V, $\Delta V_{OUT}$= +2% | | 5 | 10 | mA |
| Adjust Pin Current | $V_{IN}$=2.75V,$I_{OUT}$=10mA | | 70 | 120 | μA |
| Current Limit | $V_{IN}$=2.75V,$\Delta V_{OUT}$= -2% | 10.1 | 12.0 | | A |
| Short Circuit Current | $V_{IN}$=2.75V,$V_{OUT}$=0V | 8.0 | 10.0 | | A |
| Ripple Rejection (Note 2) | $V_{IN}$=3.25V Avg, $V_{Ripple}$=1$V_{P-P}$ @120Hz, $I_{OUT}$=4A,$C_{Adj}$=0.1μF, $C_{OUT}$=22μF | 60 | 80 | | dB |
| Thermal Regulation (Note 2) | 30ms Pulse, $T_A$=25°C | | 0.002 | | %/W |
| Dropout Voltage (Minimum $V_{IN}$ -$V_{OUT}$) (Note 3) | $I_{OUT}$=100mA<br>$I_{OUT}$=1A<br>$I_{OUT}$=2.75A<br>$I_{OUT}$=4A<br>$I_{OUT}$=10A | | 0.92<br>0.93<br>0.94<br>0.95<br>1.03 | 1.15<br>1.15<br>1.15<br>1.15<br>1.40 | V<br>V<br>V<br>V<br>V |
| RMS Output Noise | Freq=10Hz to 10kHz, $T_A$=25°C | | 0.003 | | %$V_{OUT}$ |
| Temperature Stability | | | 0.5 | | % |
| Thermal Shutdown (Note 4) | | 150 | 180 | 210 | °C |
| Thermal Shutdown Hysteresis (Note 4) | | | 25 | | °C |

Note 1: The minimum load current is the minimum current required to maintain regulation. Normally the current in the resistor divider used to set the output voltage is selected to meet the minimum load current requirement.

Note 2: This parameter is guaranteed by design and is not 100% production tested.

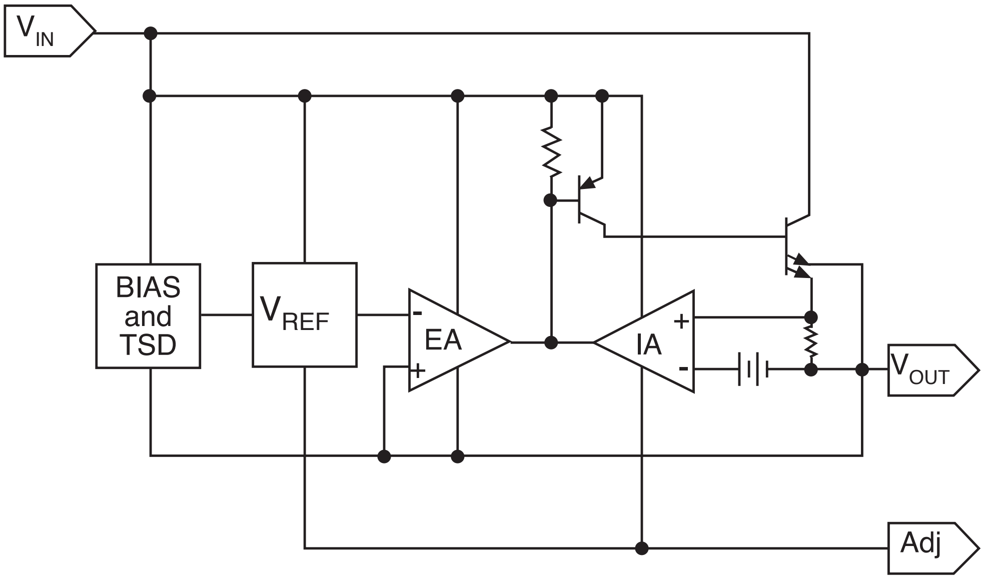
Note 3: Dropout voltage is defined as the minimum input/output voltage differential required to maintain 2% regulation.

Note 4: This parameter is guaranteed by design, but not parametrically tested in production. However, a 100% thermal shutdown functional test is performed on each part.

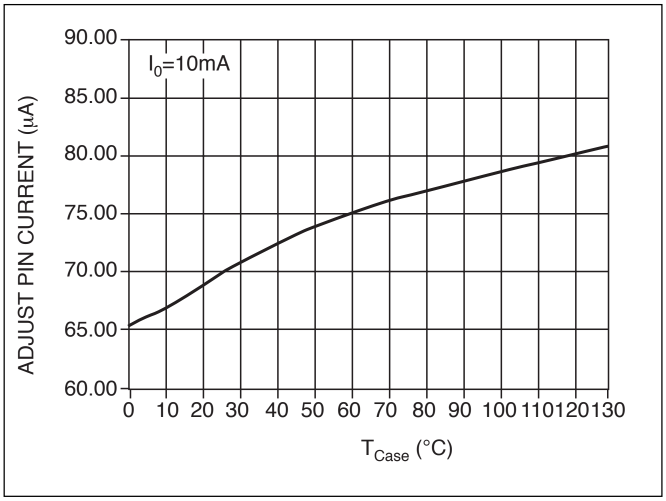
## Package Pin Description

| PACKAGE PIN # | PIN SYMBOL | FUNCTION |
|---|---|---|
| **3L TO-220** | | |
| 1 | Adjust | This pin is connected to the low side of the internally trimmed 2% bandgap reference voltage and carries a bias current of about 70μA. A resistor divider from Adj to $V_{OUT}$ and from Adj to ground sets the output voltage. Also, transient response can be improved by adding a small bypass capacitor from this pin to ground. |
| 2 | $V_{OUT}$ | This pin is connected to the emitter of the power pass transistor and provides a regulated voltage capable of sourcing 10A of current. |
| 3 | $V_{IN}$ | This is the supply voltage for the regulator. For the device to regulate, this voltage should be between 1.2V and 1.40V (depending on the output current) greater than the output voltage. |

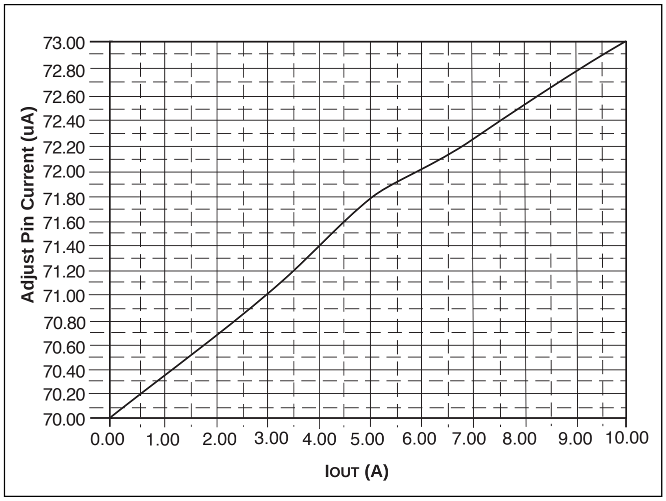
## Block Diagram



## Typical Performance Characteristics

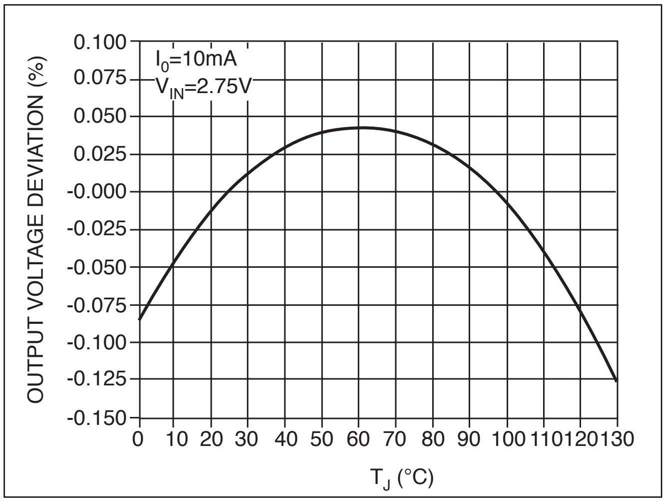


Adjust Pin Current Voltage vs Temperature

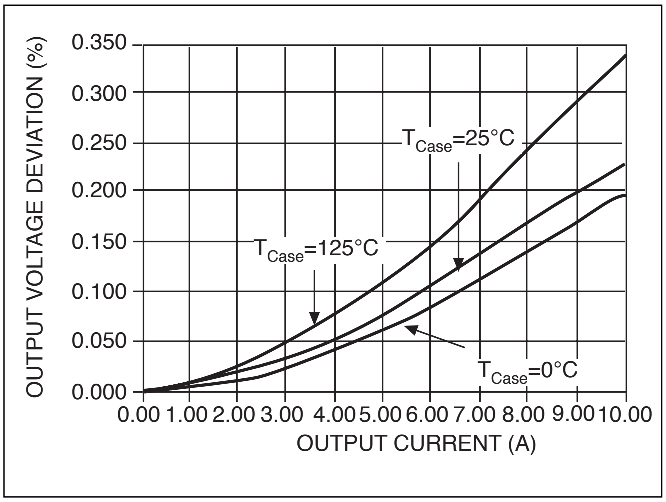


Adjust Pin Current vs $I_{OUT}$

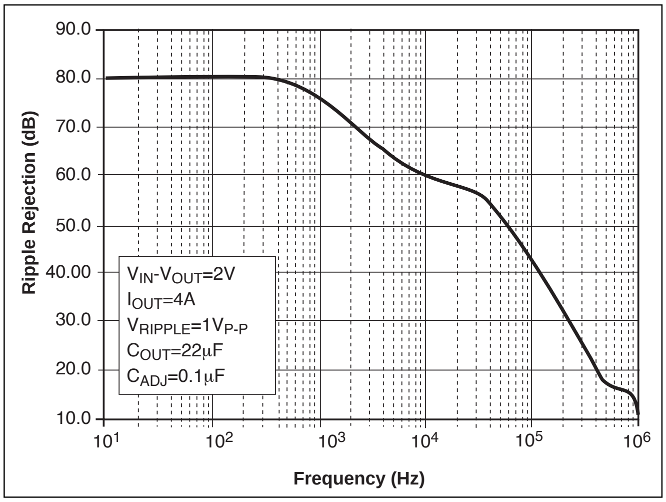
## Typical Performance Characteristics: continued



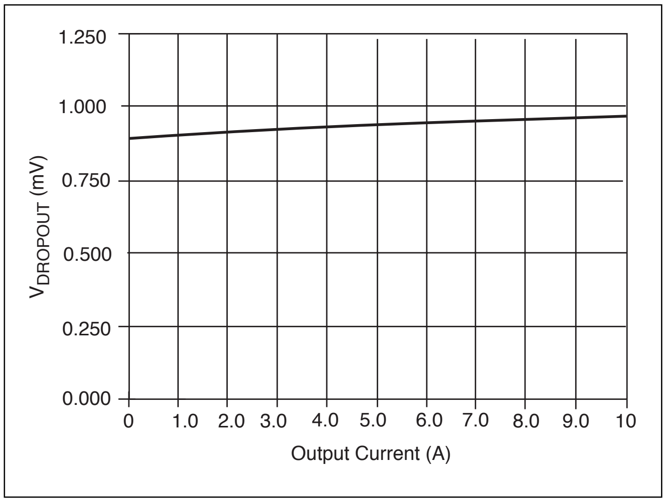
**Reference Voltage vs Temperature**



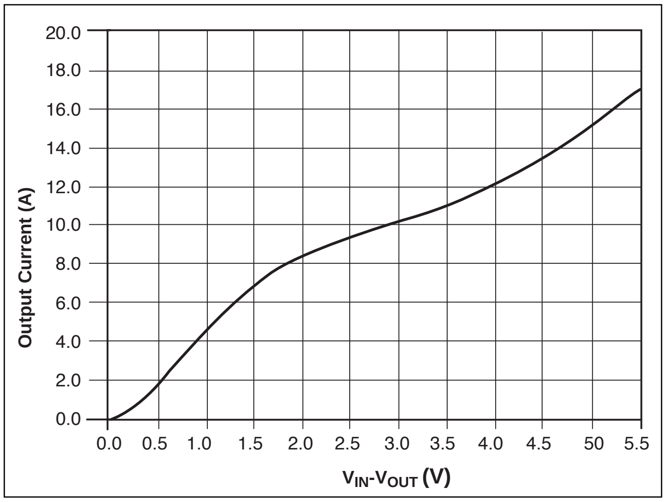
**Load Regulation vs Output Current**



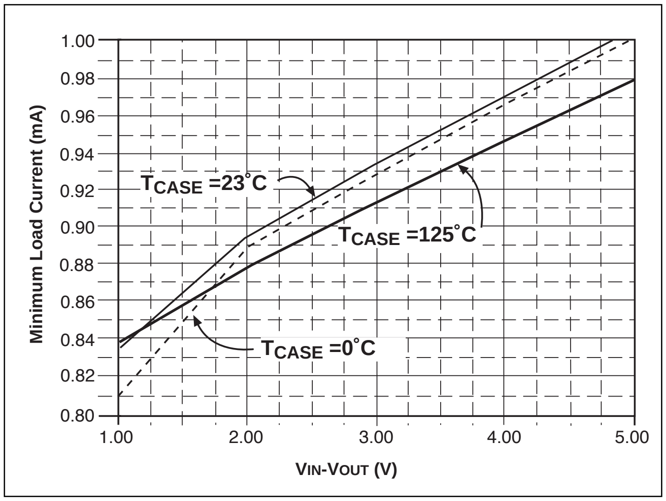
**Ripple Rejection vs Frequency**



**VDropout vs $I_{OUT}$**



**$Il_{min}$ vs $V_{IN}$ - $V_{OUT}$**



**Minimum Load Current vs $V_{IN}$-$V_{OUT}$**

## Theory of Operation

The CS5210-1 linear regulator has a composite PNP-NPN output stage that requires an output capacitor for stability. A detailed procedure for selecting this capacitor is included in the Stability Considerations section.

## Adjustable Operation

### Design Guidelines

This LDO adjustable regulator has an output voltage range of 1.25V to 4.5V. An external resistor divider sets the output voltage as shown in Figure 1. The regulator's voltage sensing error amplifier maintains a fixed 1.25V reference between the output pin and the adjust pin.

A resistor divider network $R_1$ and $R_2$ causes a fixed current to flow to ground. This current creates a voltage across $R_2$ that adds to the 1.25V across $R_1$ and sets the overall output voltage. The adjust pin current (typically 50$\mu$A) also flows through $R_2$ and adds a small error that should be taken into account if precise adjustment of $V_{OUT}$ is necessary. The output voltage is set according to the formula:

$$V_{OUT} = V_{REF} \times \frac{R_1 + R_2}{R_1} + R_2 \times I_{Adj}$$

The term $I_{Adj} \times R_2$ represents the error added by the adjust pin current.

$R_1$ is chosen so that the minimum load current is a least 10mA. $R_1$ and $R_2$ should be of the same composition for best tracking over temperature. The divider resistor should be placed as close to the IC as possible and connected to the output with a separate metal trace.

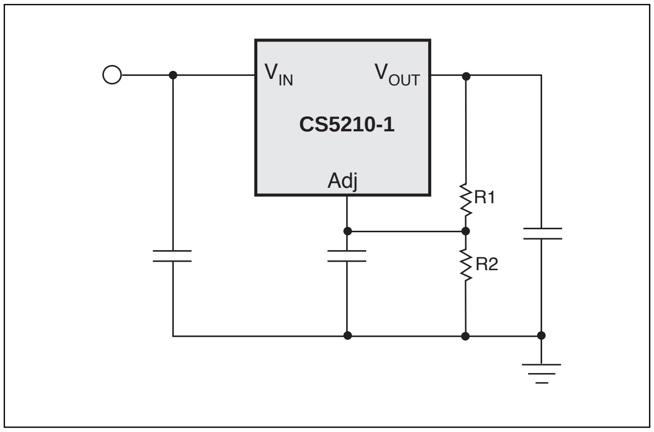


**Figure 1:**

While not required, a bypass capacitor connected between the adjust pin and ground will improve transient response and ripple rejection. A 0.1$\mu$F tantalum capacitor is recommended for "first cut" design. Value and type may be varied to optimize performance vs price.

The CS5210-1 linear regulator has an absolute maximum specification of 6V for the voltage difference between $V_{IN}$ and $V_{OUT}$. However, the IC may be used to regulate voltages in excess of 6V. The main considerations in such a design are power-up and short circuit capability.

In most applications, ramp-up of the power supply to $V_{IN}$ is fairly slow, typically on the order of several tens of milliseconds, while the regulator responds in less than one microsecond. In this case, the linear regulator begins charging the output capacitor as soon as the $V_{IN}$ to $V_{OUT}$ differential is large enough that the pass transistor conducts current. $V_{OUT}$ is essentially at ground, and $V_{IN}$ is on the order of several hundred millivolts, so that the pass transistor is in dropout. As $V_{IN}$ increases, the pass transistor will remain in dropout, and current is passed to the load until $V_{OUT}$ is in regulation. Further increase in $V_{IN}$ brings the pass transistor out of dropout. The result is that the output voltage follows the power supply ramp-up, staying in dropout until the regulation point is reached. In this manner, any output voltage may be regulated. There is no theoretical limit to the regulated voltage as long as the $V_{IN}$ to $V_{OUT}$ differential of 6V is not exceeded.

However, maximum ratings of the IC will be exceeded in a short circuit condition. Short circuit conditions will result in the immediate operation of the pass transistor outside of its safe operating area. Over-voltage stresses will then cause destruction of the pass transistor before overcurrent or thermal shutdown circuitry can become active. Additional circuitry may be required to clamp $V_{IN}$ to $V_{OUT}$ differential to less than 6V if failsafe operation is required. One possible clamp circuit is illustrated below; however, the design of clamp circuitry must be done on an application by application basis. Care must be taken to ensure the clamp actually protects the design. Components used in the clamp design must be able to withstand the short circuit conditions indefinitely while protecting the IC.

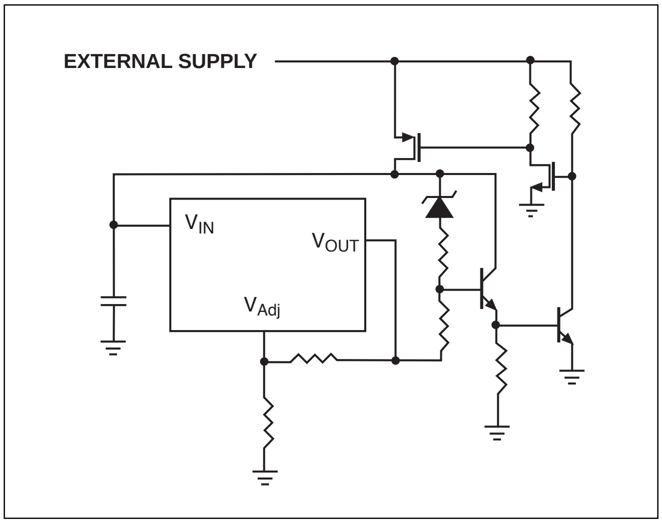


**Figure 2:**

## Stability Considerations

The output compensation capacitor helps determine three main characteristics of a linear regulator: start-up delay, load transient response, and loop stability.

The capacitor value and type is based on cost, availability, size and temperature constraints. A tantalum or aluminum electrolytic capacitor is best, since a film or ceramic capacitor with almost zero ESR can cause instability. The aluminum electrolytic capacitor is the least expensive solution. However, when the circuit operates at low temperatures, both the value and ESR of the capacitor will vary considerably. The capacitor manufacturer's data sheet provides this information.

A 300$\mu$F tantalum capacitor will work for most applications, but with high current regulators such as the CS5210 the transient response and stability improve with higher values of capacitance. The majority of applications for this regulator involve large changes in load current so the output capacitor must supply the instantaneous load current. The ESR of the output capacitor causes an immediate drop in output voltage given by:

$$\Delta V = \Delta I \times ESR.$$

For microprocessor applications it is customary to use an output capacitor network consisting of several tantalum and ceramic capacitors in parallel. This reduces the overall ESR and reduces the instantaneous output voltage drop under transient load conditions. The output capacitor network should be as close to the load as possible for the best results.

### Protection Diodes

When large external capacitors are used with a linear regulator it is sometimes necessary to add protection diodes. If the input voltage of the regulator gets shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage, and the rate at which $V_{IN}$ drops. In the CS5210-1 regulator, the discharge path is through a large junction and protection diodes are not usually needed. If the regulator is used with large values of output capacitance and the input voltage is instantaneously shorted to ground, damage can occur. In this case, a diode connected as shown in Figure 3 is recommended.

A rule of thumb useful in determining if a protection diode is required is to solve for current

$$I = \frac{C \times V}{T}, \text{ where}$$

$I$ is the current flow out of the load capacitance when $V_{IN}$ is shorted,

$C$ is the value of load capacitance

$V$ is the output voltage, and

$T$ is the time duration required for $V_{IN}$ to transition from high to being shorted.

If the calculated current is greater than or equal to the typical short circuit current valued provided in the specifications, serious thought should be given to include a protection diode.

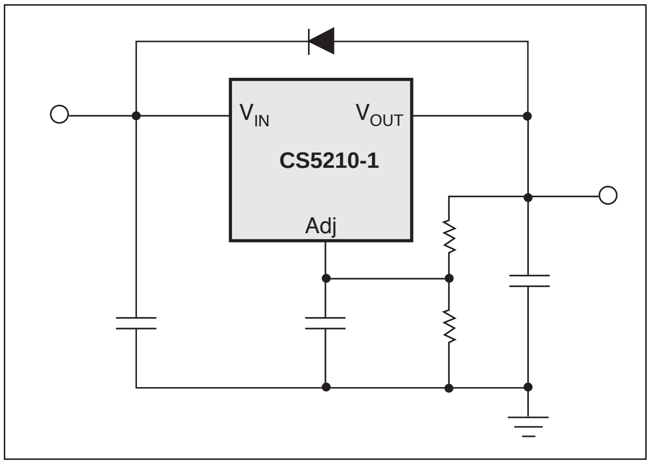


**Figure 3:**

### Current Limit

The internal current limit circuit limits the output current under excessive load conditions and protects the regulator.

### Short Circuit Protection

The device includes foldback short circuit current limit that clamps the output current at approximately two amperes less than its current limit value.

### Thermal Shutdown

The thermal shutdown circuitry is guaranteed by design to become activated above a die junction temperature of 150°C and to shut down the regulator output. This circuitry includes a thermal hysteresis circuit with 25°C of typical hysteresis, thereby allowing the regulator to recover from a thermal fault automatically.

### Calculating Power Dissipation and Heat Sink Requirements

High power regulators such as the CS5210-1 usually operate at high junction temperatures. Therefore, it is important to calculate the power dissipation and junction temperatures accurately to ensure that an adequate heat sink is used. Since the package tab is connected to Vout on the CS5210-1, electrical isolation may be required for some applications. Also, as with all high power packages, thermal compound in necessary to ensure proper heat flow. For added safety, this high current LDO includes an internal thermal shutdown circuit.

The thermal characteristics of an IC depend on the following four factors. Junction temperature, ambient temperature, die power dissipation, and the thermal resistance from the die junction to ambient air. The maximum junction temperature can be determined by:

$$T_{J(max)} = T_{A(max)} + P_{D(max)} \times R_{\Theta JA}$$

The maximum ambient temperature and the power dissipation are determined by the design while the maximum junction temperature and the thermal resistance depend on the manufacturer and the package type. The maximum power dissipation for a regulator is:

$$P_{D(max)} = (V_{IN(max)} - V_{OUT(min)})I_{OUT(max)} + V_{IN(max)} \times I_{IN(max)}$$

A heat sink effectively increases the surface area of the package to improve the flow of heat away from the IC and into the surrounding air. Each material in the heat flow path between the IC and the outside environment has a thermal resistance which is measured in degrees per watt. Like series electrical resistances, these thermal resistances are summed to determine the total thermal resistance between the die junction and the surrounding air, $R_{\Theta JA}$. This total thermal resistance is comprised of three components. These resistive terms are measured from junction to case ($R_{\Theta JC}$), case to heat sink ($R_{\Theta CS}$), and heat sink to ambient air ($R_{\Theta SA}$). The equation is:

$$R_{\Theta JA} = R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA}$$

$R_{\Theta JC}$ is rated @ 1.4°C/W for the CS5210-1. For a high current regulator such as the CS5210-1 the majority of heat is generated in the power transistor section. The value for $R_{\Theta SA}$ depends on the heat sink type, while the $R_{\Theta CS}$ depends on factors such as package type, heat sink interface (is an insulator and thermal grease used?), and the contact area between the heat sink and the package. Once these calculations are complete, the maximum permissible value of $R_{\Theta JA}$ can be calculated and the proper heat sink selected. For further discussion on heat sink selection, see our Cherry application note “Thermal Management for Linear Regulators.”

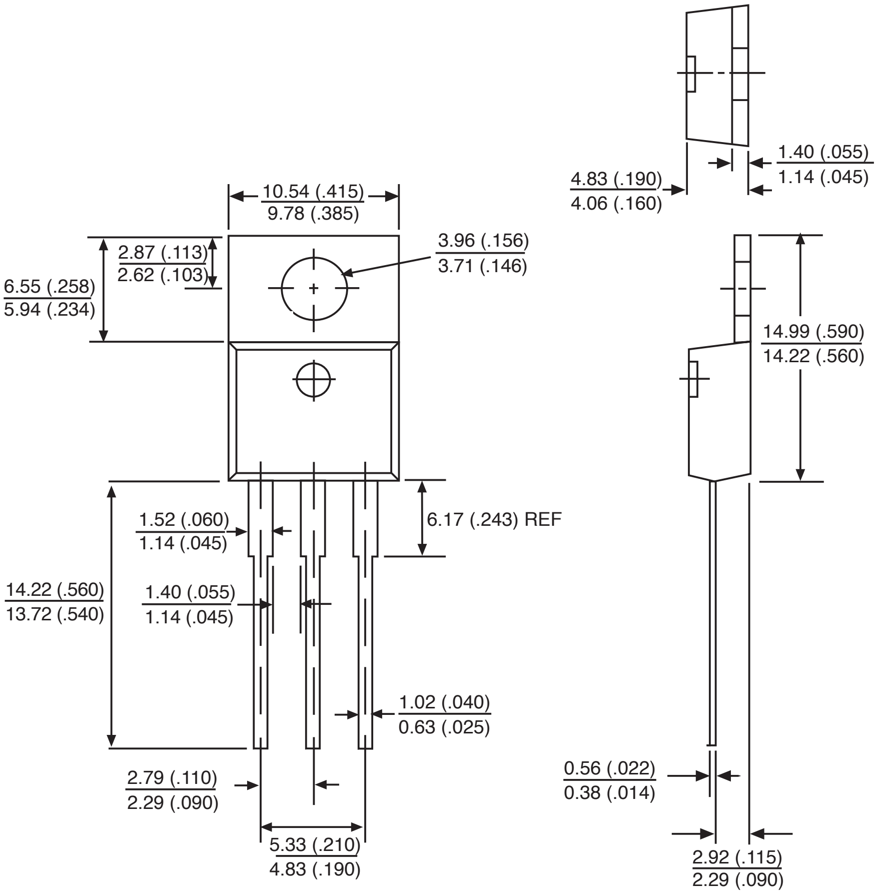
## Package Specification

### PACKAGE DIMENSIONS IN mm (INCHES)

### PACKAGE THERMAL DATA

| Thermal Data | | 3L<br>TO-220 | |
|---|---|---|---|
| $R_{\Theta JC}$ | typ | 1.4 | °C/W |
| $R_{\Theta JA}$ | typ | 50 | °C/W |

### 3 Lead TO-220 (T) Straight



### Ordering Information

| Part Number | Description |
|---|---|
| CS5210-1GT3 | 3L TO-220 Straight |

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