Linear Regulators and Trackers Protection Circuits

Linear Voltage Regulators

Z8F52274292

Application Note

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Automotive Power

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1 Abstract

Infineon automotive linear voltage regulators and trackers contain protection circuits to prevent the IC from destruction in case of possible catastrophic events. These safeguards comprise

- output current limitation
- overvoltage protection
- reverse polarity protection
- thermal shutdown in case of overtemperature.

However, dependent on silicon technology and pass element selection, different circuitry is implemented. The following explains these protection features and their impact to the application circuit.

2 Thermal Shutdown

All automotive linear regulators are designed to withstand a junction temperature of up to 150 °C. Package and heat sink selections need to ensure that the maximum junction temperature is not exceeded under any operating condition. For information on a package's thermal capability, see the Infineon brochure "Thermal Resistance – Theory and Practice".

However, in order to prevent the IC from immediate destruction under fault conditions (e.g. permanent short-circuit at output), a thermal shutdown is integrated on chip. The circuitry switches off the power stage in the junction temperature range of 151 °C to 200 °C, unless otherwise specified. After cooling down of the chip, the regulator restarts. This leads to an oscillatory behavior of the output voltage until the fault condition is removed.

Junction temperatures above 150 °C are outside the maximum ratings and therefore significantly reduce the IC lifetime.

3 Reverse Polarity

When applying a negative battery voltage, unwanted current flows through various paths dependent on the type of regulator and its load (see **Figure 1**).

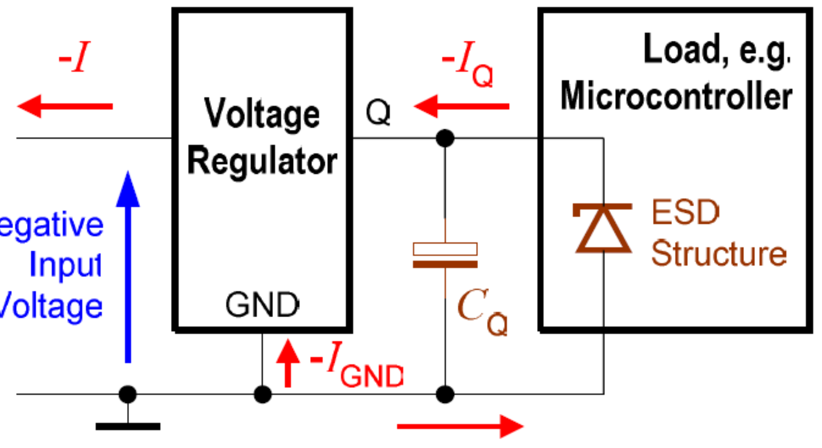

Figure 1 Currents flowing in case of negative supply

A current may flow into the GND pin of the regulator as well as into the output pin Q. Dependent on the silicon process used for the IC, different considerations apply[1)]:

3.1 NPN Bipolar Voltage Regulators (TLE4x8x only)

Regulators with an NPN pass transistor offer no reverse polarity protection. If the input voltage is lower than the output voltage, an unlimited current will flow through parasitic junctions. Hence a blocking diode at the input is needed to withstand a steady state reverse battery condition. This series diode adds an additional drop and must be sized to hold off the system's maximum negative voltage as well as the regulator's maximum output current.

3.2 PNP Bipolar Voltage Regulators and Trackers (TLE4xxx, except TLE4x8x)

Regulators with a PNP pass transistor allow a negative supply voltage. (See data sheet for the maximum value.) However, a reverse supply voltage causes several small currents flowing into the IC increasing its junction temperature. This has to be considered for the thermal design, respecting that the integrated thermal shutdown circuitry does not working during reverse polarity condition.

Typical reverse currents of a bipolar PNP regulator are shown in the graphs below (**Figure 2**). The following situations might occur in an automotive environment:

- Output voltage higher than input voltage (e.g. $V_I = 0$ V, $V_Q = 5$ V).
- Input open, positive output voltage applied.(i.e. $V_I = V_Q$).
- Input voltage negative, output tied to GND (applies if a current can flow through the clamping structure of the load).

1) For characteristics and differences between “Bipolar” and “SPT” voltage regulators, see the application note »Silicon Technologies for Linear Regulators«.

Figure 2 and **Figure 3** give an example for Infineon bipolar PNP voltage regulators.

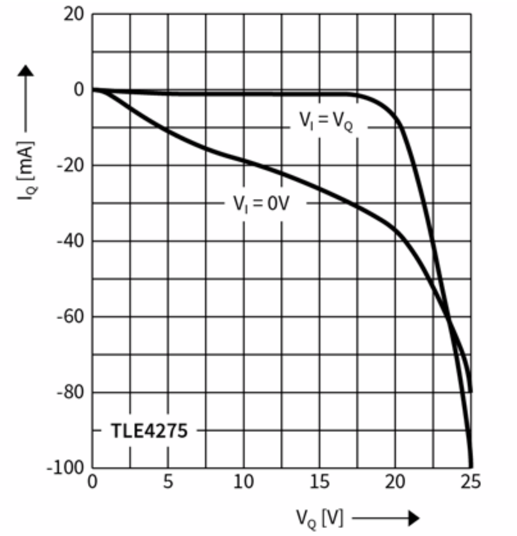

Figure 2 Reverse Current Example (TLE4275), Positive voltage applied to the output Q.

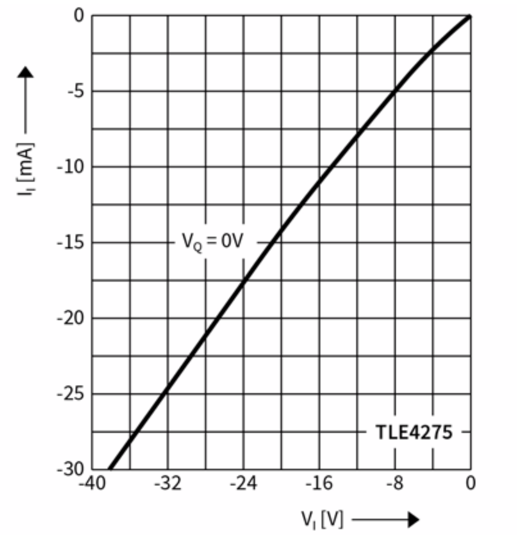

Figure 3 Reverse Current Example (TLE4275), Negative voltage applied to the input I

3.3 NMOS Voltage Regulators (TLE7xxx)

TLE7xxx family Voltage Regulators use an N-channel MOSFET as pass element and diode structures from the input to ground. In case of a negative input voltage condition, an unlimited reverse current would flow through the MOSFET's reverse diode as well as into the GND pin. Therefore, a series diode at the IC input is mandatory. (Commonly, a diode in the battery line is present on the board anyway.) During normal operation, the diode will be forward biased adding an additional drop voltage to the system. Therefore, a Schottky diode is recommended.

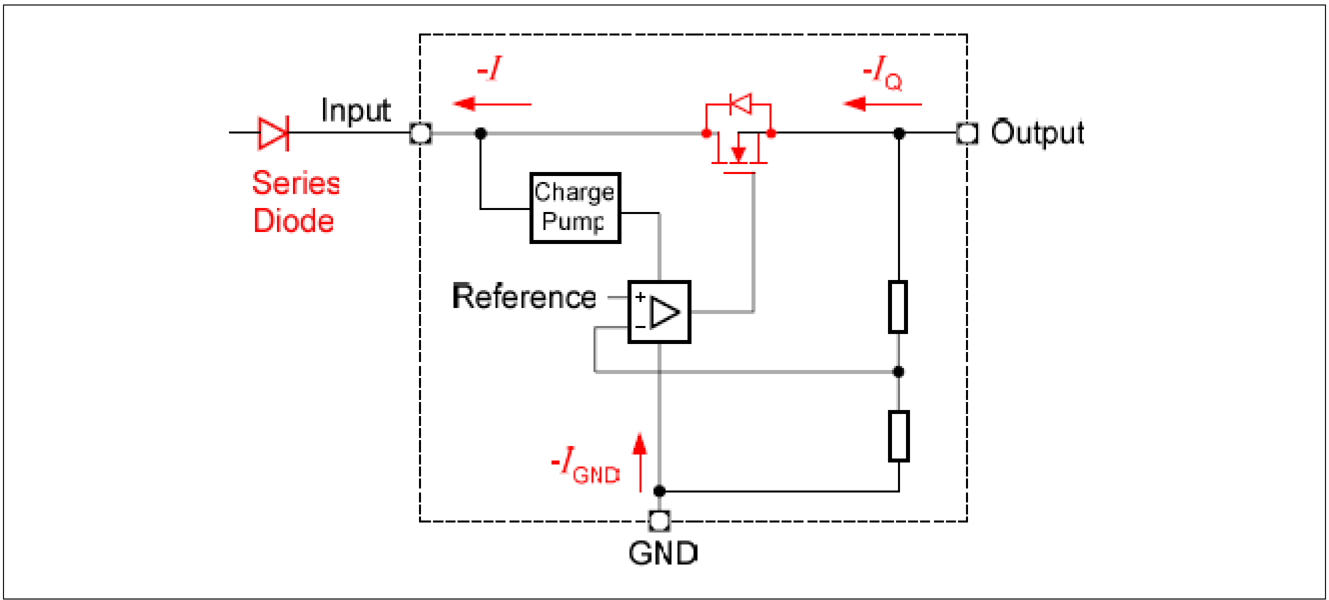

Figure 4 NMOS Voltage Regulator, Currents flowing during reverse supply conditions

Also, at the inhibit (INH) input, respectively enable (EN) input, a negative voltage must not be applied. However, in order to allow negative transients, a high-ohmic resistor can be added in series to protect the input structure (see **Figure 5**). The maximum negative current must not exceed 0.5 mA.

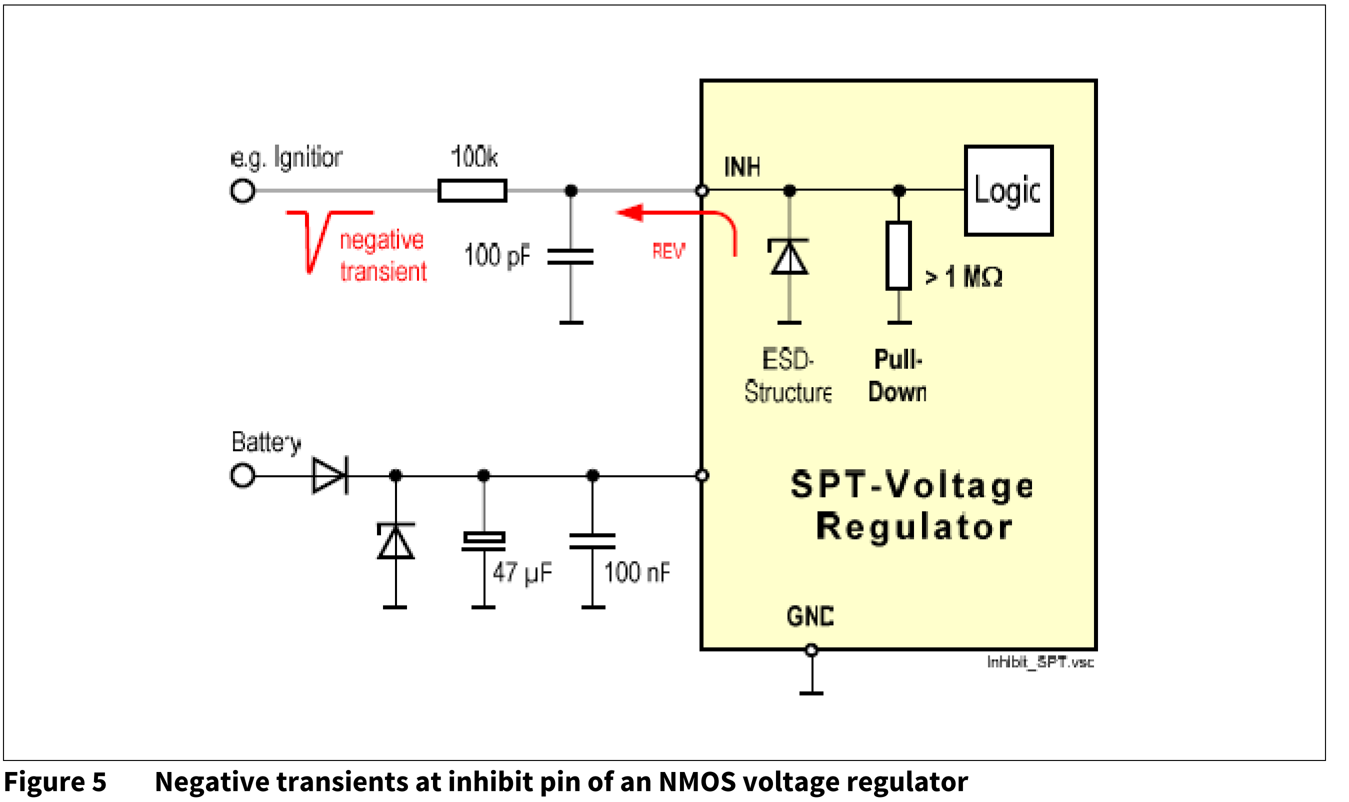

Figure 5 Negative transients at inhibit pin of an NMOS voltage regulator

4 Overvoltage

High voltage transients are generated by inductive loads like motor windings or long wire harnesses. In order to provide sufficient protection in an automotive environment, Infineon uses transistor structures that withstand a continuous supply voltage up to V_I = 45 V. Additionally, several ICs offer protection against load dump pulses up to 65 V (e.g. TLE4270, TLE4271-2). For details see the “Absolute Maximum Ratings” table in the data sheet. Exceeding any of these values may destroy the IC independent from pulse length. Therefore, a suppressor diode is suggested to protect from overvoltage. Moreover, transients can be buffered with an input capacitor that takes the entire or a portion of the energy, attenuating the surge at the IC input pin I.

For protecting the voltage regulator output against short circuit to battery, the maximum voltage allowed at the output Q is much higher than the nominal output voltage. Therefore, all trackers and many voltage regulators tolerate an output voltage up to V_Q = 45 V. See data sheet for details. Information on the reverse current is given in the section “Reverse Polarity” of that document.

5 Current Limitation

In case of short-circuiting the output to GND or in case of excessive load condition, the regulator is forced to deliver a very high output current. To prevent the application as well as the regulator itself from destruction, the IC limits the output current to a reasonable value specified in the data sheet.

For controlling the short-circuit current, two types of protection on chip are common: constant or foldback current limitation. Infineon linear regulators use a Constant Current Limitation in order to overcome “latch-up” problems with the foldback limiting method: If the load draws a current anywhere along the foldback curve after removing the fault condition, the output will never reestablish its original voltage.

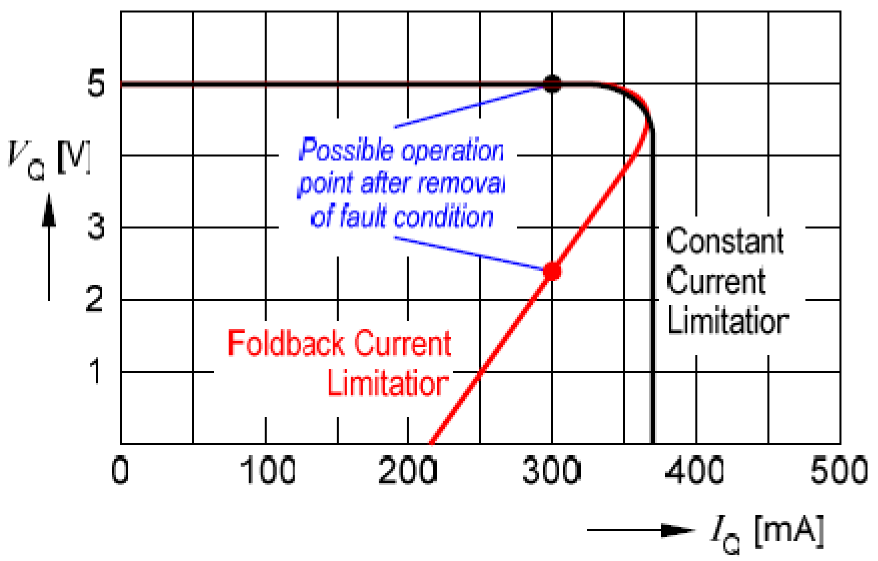

Figure 6 Constant and Foldback Current Limitation

During startup, the output capacitor is charged with the maximum output current. Hence, the time until nominal output voltage is reached after turning on the IC, respectively applying an input voltage, calculates as follows: $t_{STARTUP} = V_Q \times C_Q / (I_{Q,MAX} - I_{LOAD})$.

6 Safe Operation Area

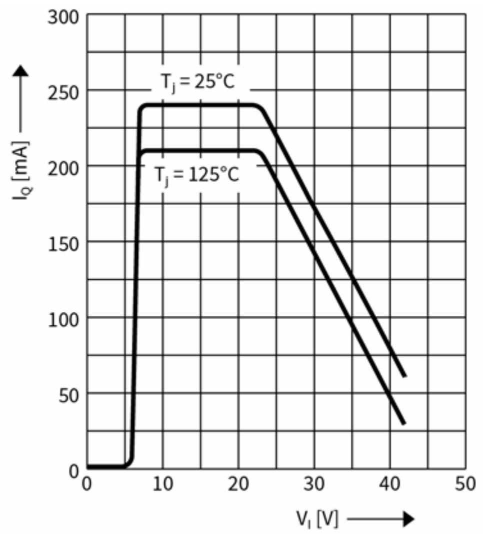

Figure 7 Maximum Output Current versus Input Voltage (Safe Operation Area). Typical graph for bipolar regulators.

In order to avoid excessive power dissipation that never could be handled by the pass element and the package, Infineon's bipolar voltage regulators decrease the maximum output current (short circuit current) at input voltages above 22 V. That means that the rated output current of the regulator is not reached at very high input voltages. See **Figure 7**.

7 Conclusion

Infineon linear regulators provide all relevant protection circuits needed to protect the application and the IC itself in a typical automotive environment. The implemented circuitry reduces external components to a minimum and therefore significantly increases the cost-effectiveness of Infineon regulators.

8 Frequently Asked Questions

- At which temperature exactly does the regulator switch off?
  The shutdown temperature is subject to production spread but is chosen to ensure proper operation up to a junction temperature of T_j = 150°C. The protection feature is intended to prevent the IC from immediate destruction. Hence, the shutdown circuitry is not adjusted, switching off the regulator between 151 °C and 200 °C. The thermal design must ensure the maximum junction temperature under all operation conditions. Repetitive operation above 150 °C significantly decreases the IC lifetime.
- Why does output voltage toggle periodically at high output current?
  Possibly, the regulator runs into thermal shutdown at high load and high input voltage causing more power dissipation than the package and the thermal design can handle. After switching off the power stage, the chip cools down and restarts when the temperature falls below the lower temperature threshold with a hysteresis of typically 40 Kelvin. This “thermal toggling” is visible until the overload condition is removed.
- I would like to apply transients up to 100V to the supply line. Can the regulator withstand this voltage for a short period of time?
  The maximum voltage at the input pin needs to comply with the “Maximum Ratings” given in the data sheet. Exceeding any value may destroy the IC independent from pulse length. Therefore, a suppressor diode is suggested to protect from overvoltage. Moreover, transients can be buffered with an input capacitor that takes the entire or a portion of the energy attenuating the surge at the IC input pin I.
- Does “Reverse Polarity Proof” mean that no reverse current is flowing?
  “Reverse Polarity Proof” means that a negative supply voltage can be applied at a PNP regulator without immediately destructing the IC. However, a limited reverse current is flowing to the input. Dependent on input voltage, this current causes some power dissipation heating up the IC. If the reverse current is not desired, a blocking diode at the input is needed.
- Which voltage will establish at the output of a voltage regulator when a negative input voltage is applied?
  Since a reverse current is flowing in case of negative input voltage, a negative voltage will also establish at the output, depending on reverse current and load. This means that some current might flow through the clamping circuitry of the load.

9 Revision History

Revision	Date	Changes
1.11	2015-03-10	Infineon Style Guide update. Editorial changes.

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Do you have a question about any aspect of this document?

Email: erratum@infineon.com

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