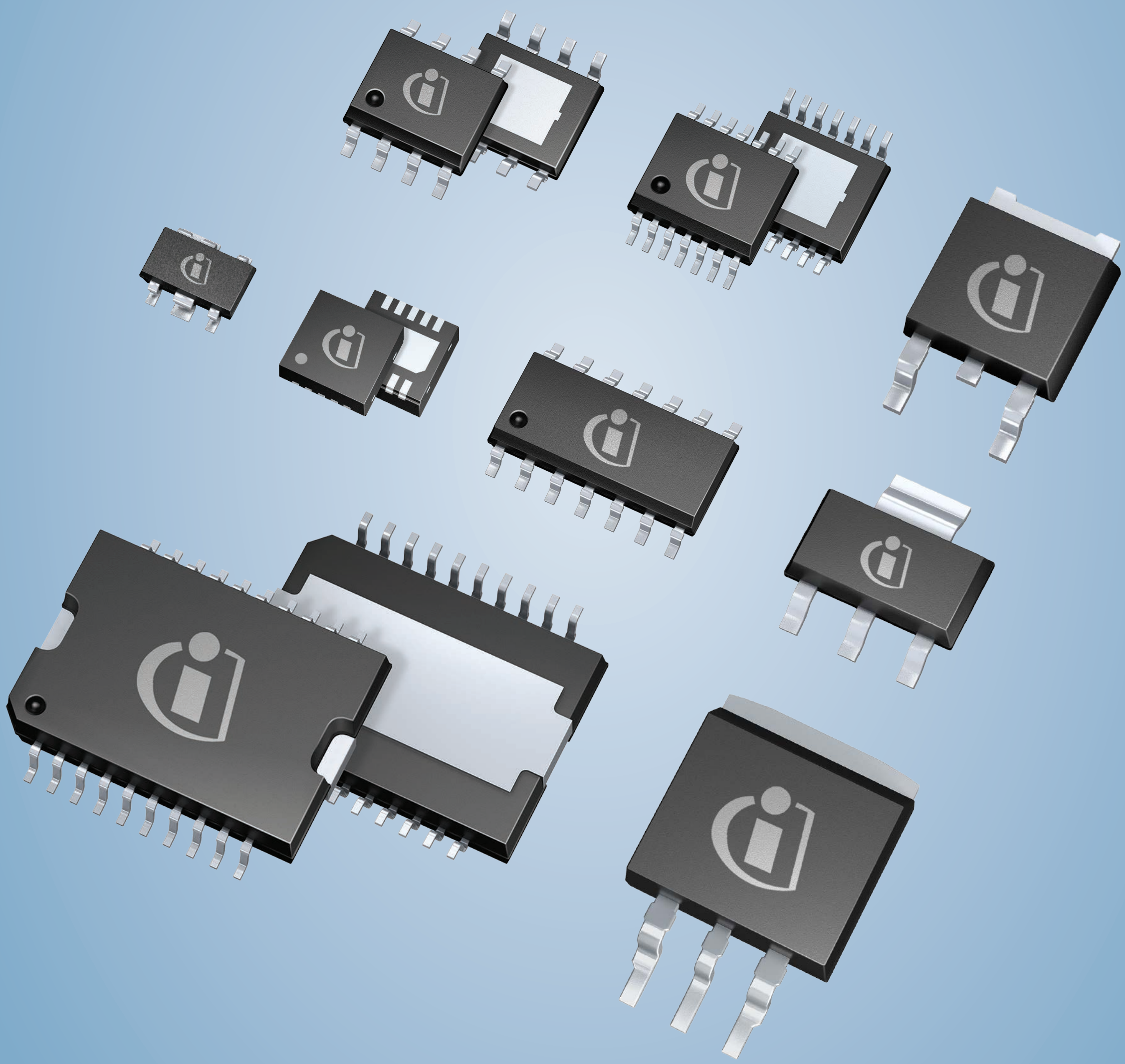


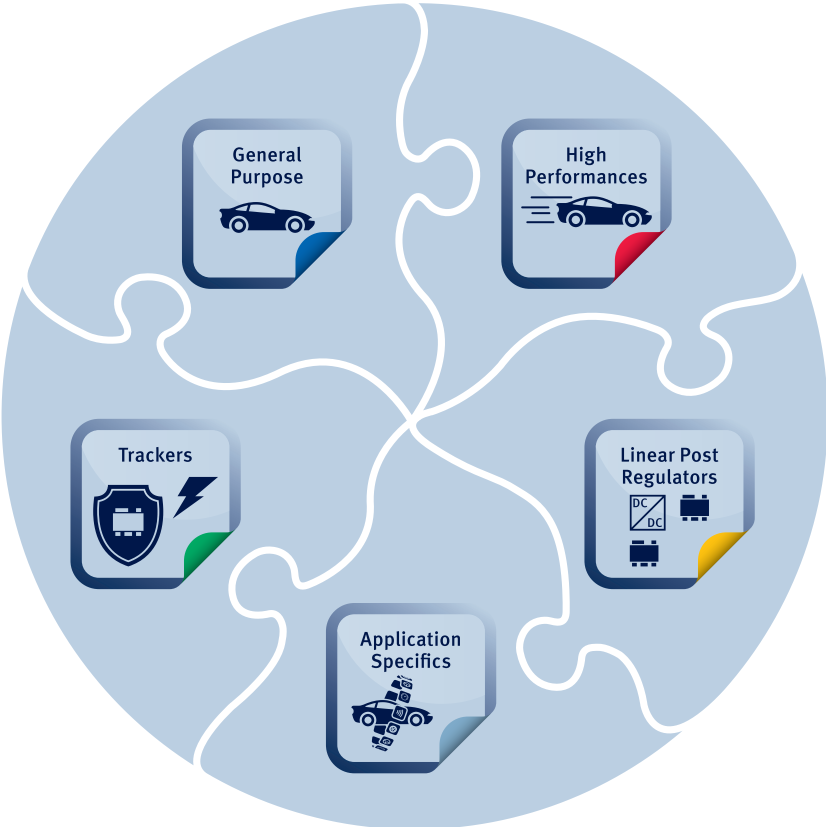
What the Designer Should Know

Introduction to Automotive Linear Voltage Regulators

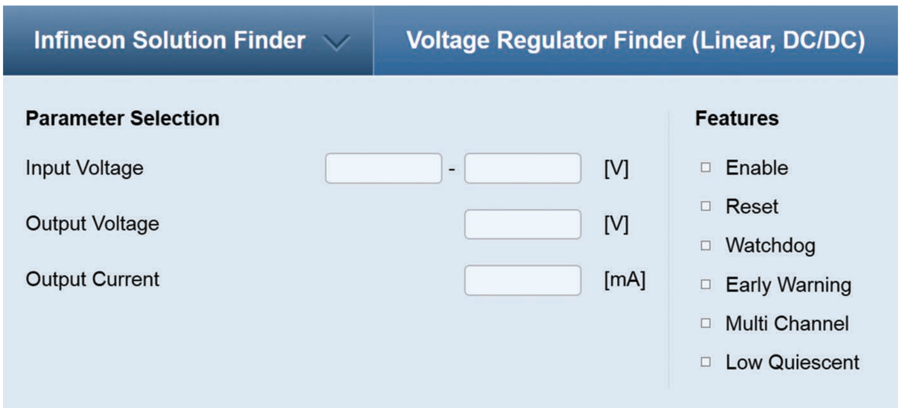
Issue 2014

www.infineon.com/voltage-regulator

Product Family Portfolio



New easy to use Selection Tool

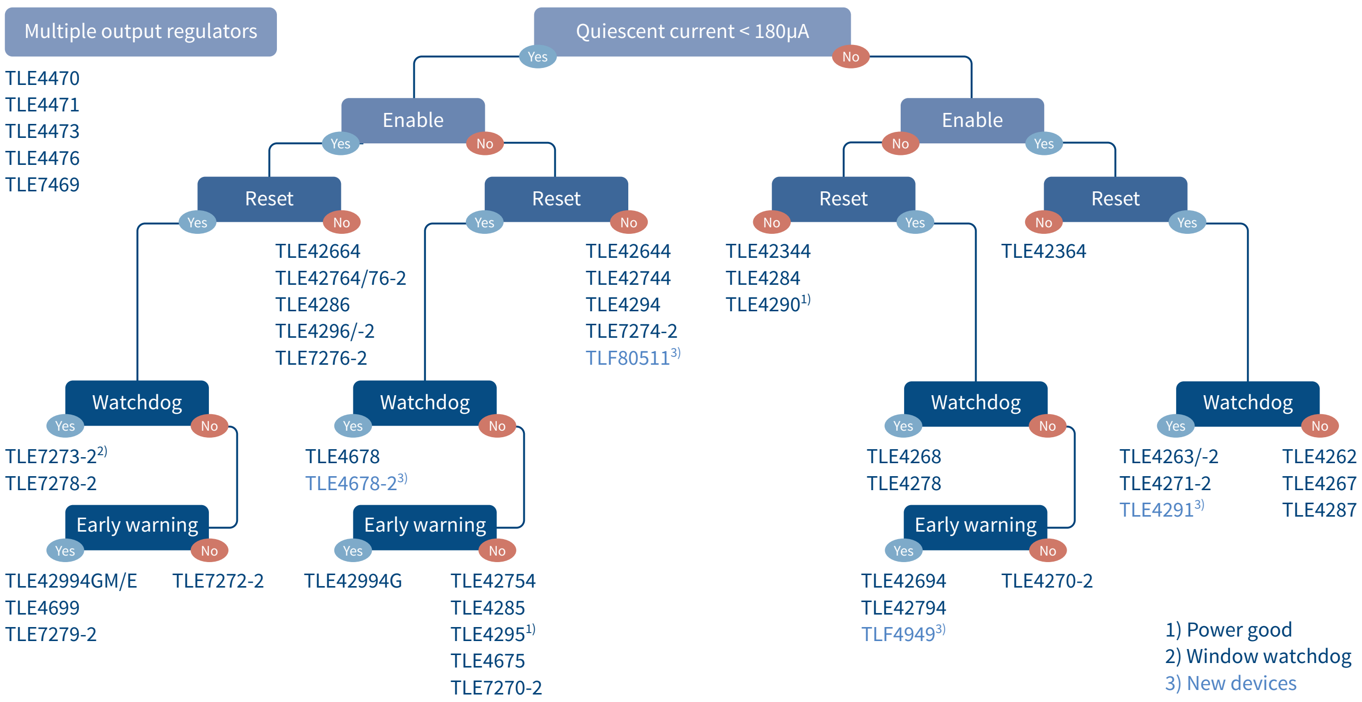


www.infineon.com/vreg-finder

All products are Automotive qualified and RoHS compliant

Content

Linear Voltage Regulator



Selection tree

Key features

- Standard features
  - Wide operation range up to 45V
  - Low dropout voltage
  - Wide temperature range: -40°C up to +150°C
- Standard protections
  - Short-circuit protection
  - Reverse polarity protection as option
  - Overload protection
  - Overtemperature protection

Enable function for main output
Low quiescent current consumption in standby mode

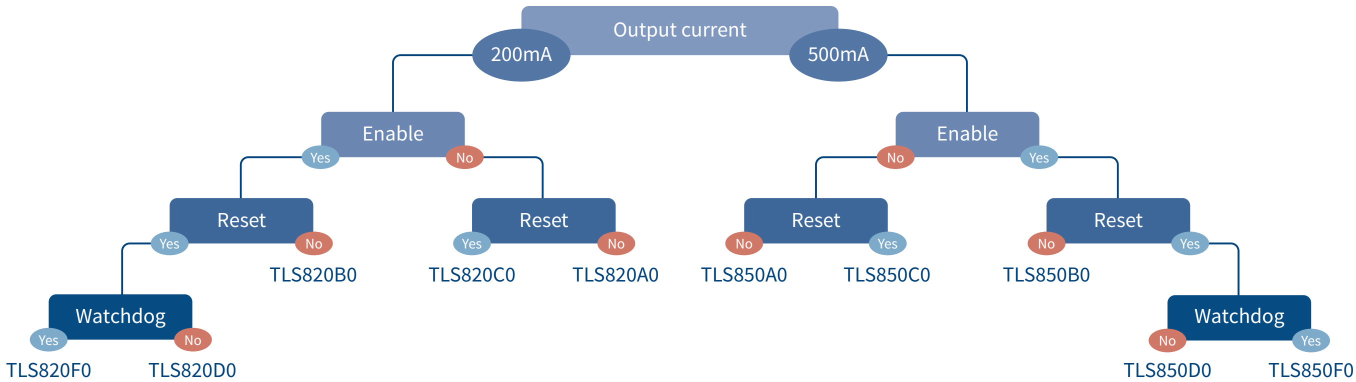
Adjustable reset function
Power-on reset circuit sensing the standby voltage

Standard and window watchdog

Early-warning comparator for sensing input undervoltage

High Performance Linear Voltage Regulator

Infineon's Future Linear Voltage Regulator Family

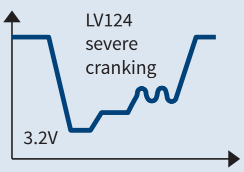


1) None contractual product proposal: for more information on product family contact sale relations

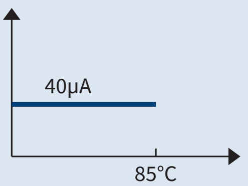
Selection tree

Key features

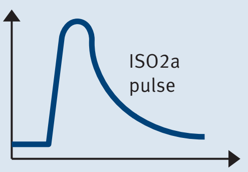
Ultra Low Drop Voltage



Low Quiescent Current



Excellent Line & Load Transient



Key benefits

Suitable for very low cranking (stop and start)

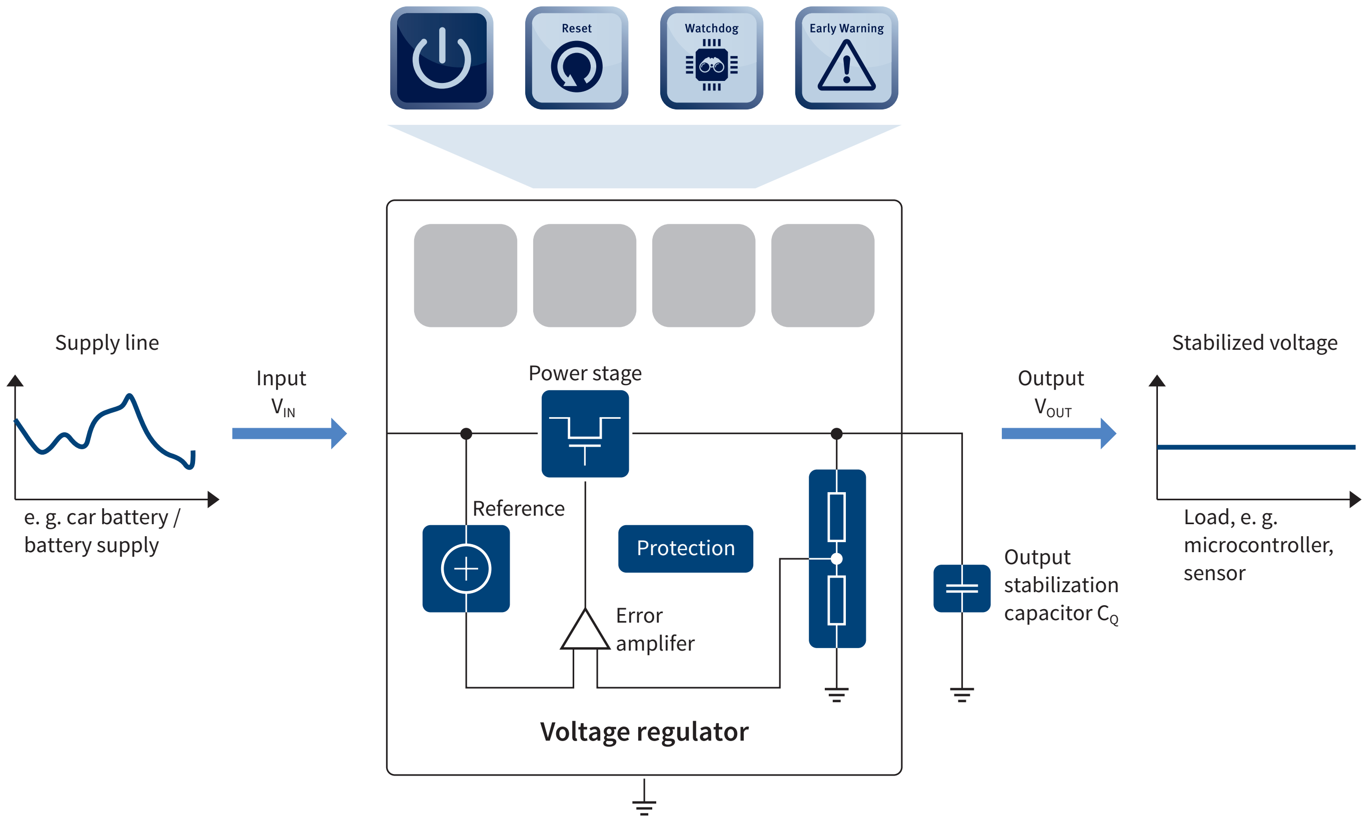
Save battery resources for ECUs in ON-state

Design for harsh automotive environment

RoHS

AEC Qualified

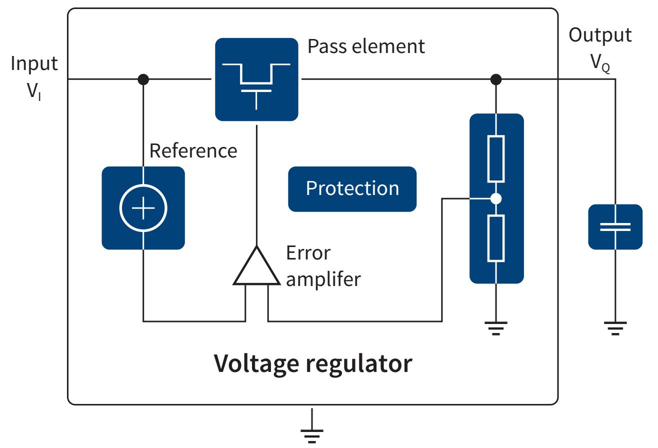
Infineon's Automotive Linear Voltage Regulators



Why do we need linear voltage regulators?

In automotive ECUs, microcontrollers and other parts of the system have to be supplied by a stable and reliable voltage that is lower than the battery voltage (e.g. 3.3V or 5V) and works over the entire temperature range (from -40°C to 150°C). Use of discrete solutions does not manage to fulfill those conditions because of voltage dependency on load-current (e.g. resistor divider) or on temperature (e.g. Zener diode).

A linear voltage regulator converts a DC input voltage (e.g. battery line) into a pre-defined lower DC output voltage (e.g. 5V). In spite of input voltage variations, the output voltage remains steady and stable, as long as the input voltage is greater than the output voltage. Linear voltage regulators are the most frequently used electronic power supplies in automotive applications.



Linear voltage regulator block diagram

How does a linear voltage regulator work?

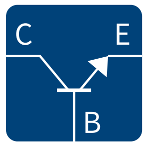
Every linear voltage regulator consists of an internal reference voltage, an error amplifier, a feedback voltage divider and a pass transistor. The output current is delivered via the pass element controlled by the error amplifier. The error amplifier compares the reference and output feedback voltages.

If the output feedback voltage is lower than the reference, the error amplifier allows more current to flow through the pass transistor, hence increasing the output voltage.

On the contrary, if the feedback voltage is higher than the reference voltage, the error amplifier allows less current to flow through the pass transistor, hence decreasing the output voltage.

Different types of pass element

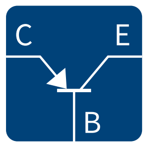
NPN linear regulators



NPN transistor

Conventional linear regulators use NPN bipolar transistors as the pass element. Usually the pass element is composed of a PNP base current driver transistor and a single NPN power transistor, therefore the drop voltage, i.e. the minimum voltage difference between input and output, is equal to V_{SAT}(PNP) + V_{BE}(NPN), which is about 1.2V. Functionalities and integrated protection are limited and additional protection circuitries are required.

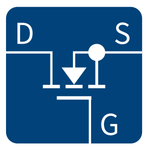
PNP linear regulators



PNP transistor

With only a single PNP bipolar transistor as the pass element, the drop voltage of PNP regulators is about 0.5V. For this reason, this type of regulator is called Low Drop Out (LDO). This enables it to operate during a drop in battery voltage (e.g. cranking). PNP regulators are protected against reverse polarity faults.

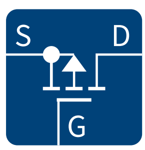
NMOS linear regulators



NMOS

NMOS pass transistors provide very low drop-out voltage and minimal quiescent current. A charge pump is necessary to achieve low drop-out voltage, because the gate of the NMOS needs to be ~2V higher than the voltage at source to drive the pass element open. However, the change pump also introduces additional line noise.

PMOS linear regulators

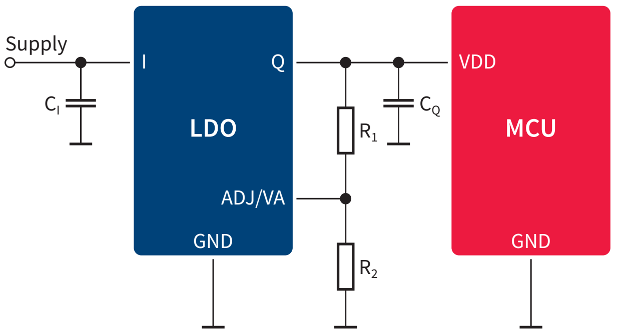


PMOS

PMOS linear regulators provide very low drop-out voltage and minimal quiescent current. An internal charge pump is not necessary for the PMOS pass element. The new control loop concept in the new Infineon PMOS linear regulators allows a faster regulation loop and better stability, requiring only a single 1µF output capacitor for stable operation.

Adjustable output voltage

The output voltage of some linear voltage regulators can be adjusted by an external resistor divider, connected to the voltage adjust pin named as ADJ or VA.



Application diagram

For a certain output voltage, the value of the external resistors can be easily calculated with the formula:

$$V_Q = V_{ref} \times \left(\frac{R_1 + R_2}{R_2}\right)$$

Where:

- $R_2 < 50k\Omega$ to neglect the current flowing into the ADJ/VA pin.
- Internal reference voltage V_{ref} is device-dependent. The V_{ref} value of a specific device can be found in its datasheet.

If an output voltage equal to the reference voltage is needed, the output pin Q has to be directly connected to the voltage adjust pin ADJ/VA.

Example:
Selection of the external resistors for TLE42764GV/DV

According to the datasheet

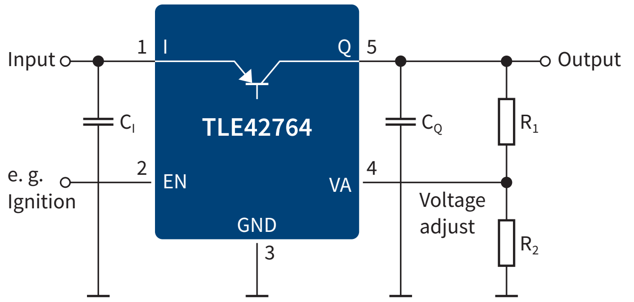
- Internal reference voltage V_{ref}: typically 2.5V,
- Output voltage V_{OUT} adjustable between 2.5V and 20V,

Required output voltage: V_{OUT} = 3.3V.

The following resistors could be selected:

- $R_1 = 12k\Omega$, $R_2 = 39k\Omega$

It must be taken into consideration that the accuracy of the resistors R_1 and R_2 adds an additional error to the output voltage tolerance.



Application diagram TLE42764GV/DV

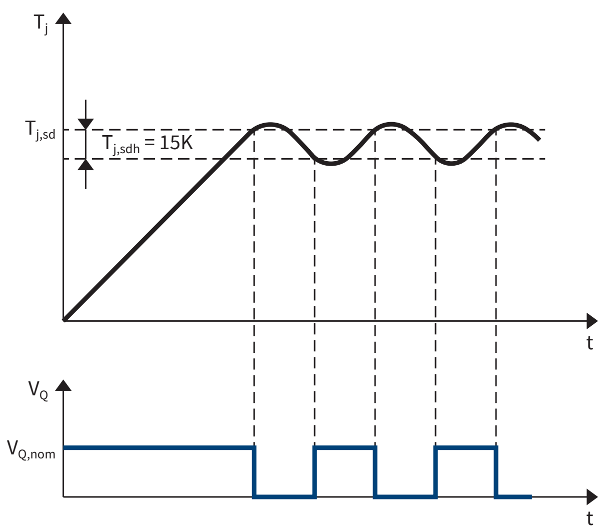
Embedded Protections

Thermal shutdown

Infineon's automotive linear regulators are designed to withstand junction temperatures up to 150°C. Package and heat sink selections need to ensure that the maximum junction temperature is not exceeded in any operating condition.

To prevent IC damage in fault conditions (e.g. output continuously short-circuited), a thermal shutdown has been integrated. The circuitry switches off the power stage for a junction temperature higher than 151°C, typically 175°C, unless otherwise specified in the datasheet. The device re-starts automatically after cooling down with a typical hysteresis of 15K (e.g. with a thermal shut-down at 175°C, re-start occurs at 160°C).

Temperature above 150°C is outside the maximum ratings of the voltage regulators and reduces the IC lifetime significantly.



Thermal shutdown and hysteresis

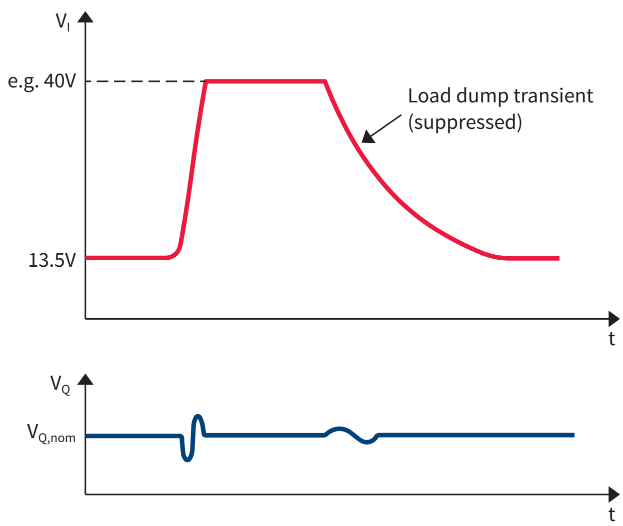
Overvoltage

High voltage transients are generated by inductive loads (e.g. motor windings or long wire harnesses). In order to provide sufficient protection in an automotive environment, e.g. the load dump voltage, Infineon uses transistor structures withstanding a continuous supply voltage V_I up to 45V. Additionally, several ICs offer protection against load dump pulses up to 65V (e.g. TLE4270, TLE4271-2).

For details please refer to "Absolute Maximum Ratings" table in datasheet.

Exceeding any of these values may damage the IC independent of pulse length. Therefore, a suppressor diode is suggested to provide protection from overvoltage. Moreover, transients can be buffered with an input capacitor that takes the entire energy or some of it, attenuating the surge at the IC input pin I.

In order to protect the voltage regulator output against short circuits to the battery, the maximum voltage allowed at the output Q is much higher than the nominal output voltage. Therefore, all trackers and some voltage regulators tolerate an output voltage up to V_Q = 45V, which protects them against shorts to battery at the output.



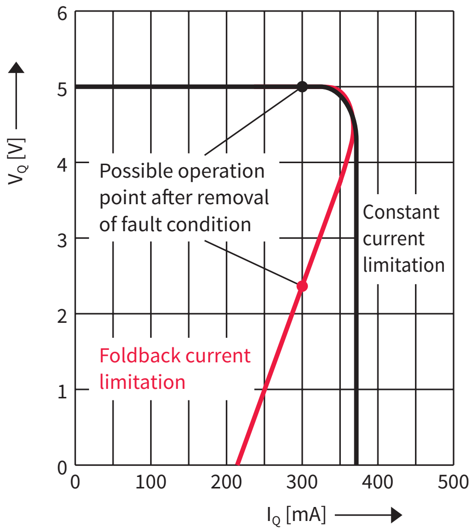
Load dump transient

Current limitation

In case of short-circuiting the output to GND or under excessive load conditions, the regulator is forced to deliver a very high output current. To protect the application as well as the regulator itself against damage, the IC limits the output current. Values are specified in the datasheet.

Two types of protection could be implemented: constant or fold-back current limitation. Infineon linear regulators use constant current limitation in order to overcome "latch-up" problems with the fold-back limiting method: If the load draws a current anywhere along the fold-back curve after the removal of the fault condition, the output will never reestablish its original voltage.

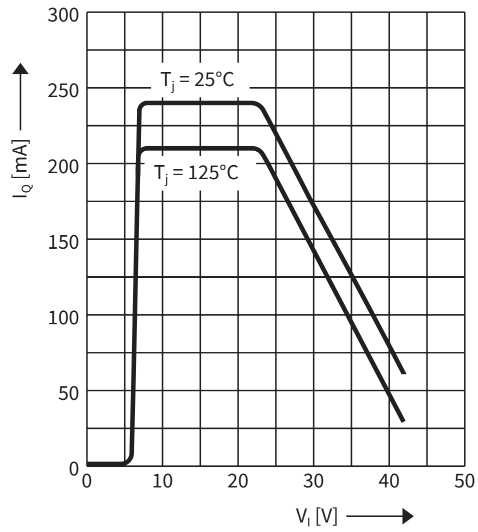
During start-up, the output capacitor is charged up with the maximum output current. Hence, the time until nominal output voltage is reached after turning on the IC or applying an input voltage is calculated as $t_{STARTUP} = V_Q \times C_Q / I_{Q,MAX}$.



Current limitation

Safe operating area

In order to avoid excessive power dissipation which cannot be handled by the package, the voltage regulator decreases the maximum output current (short-circuit current) at input voltages above a certain voltage, e.g. 22V. That means that at very high input voltages, the regulator is not able to deliver the full (specified) output current.

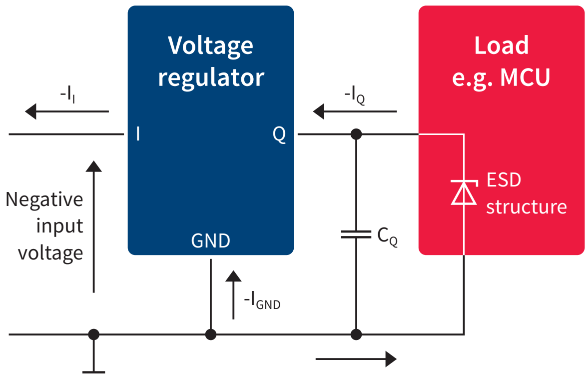


Maximum output current vs. input voltage (typical graph of TLE4678)

Reverse polarity

The following reverse polarity situations might occur in the automotive environment:

- Output voltage higher than input voltage (e.g. V_I = 0V, V_Q = 5V.)
- Input open, positive output voltage applied (i.e. $V_I = V_Q$).
- Input voltage negative, output tied to GND.

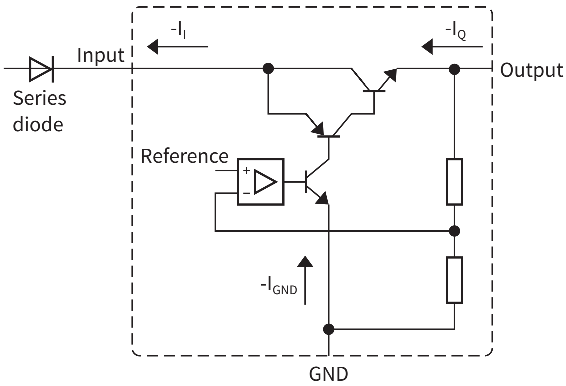


Reverse current in the voltage regulator

In reverse polarity situations, current may flow into the GND pin of the regulator as well as into the output pin Q. Depending on the type of the pass transistor, different protection should be applied:

NPN bipolar voltage regulators (TLE4x8x)

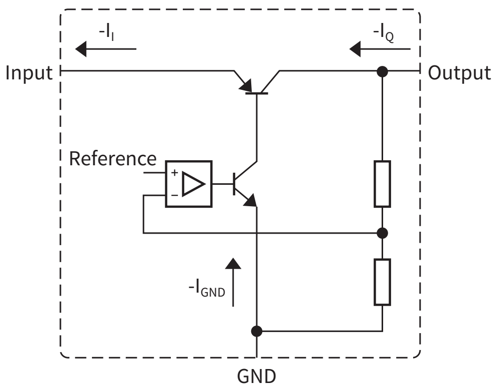
Linear voltage regulators with an NPN pass transistor offer no reverse polarity protection. If the input voltage is lower than the output voltage, an unlimited current will flow through parasitic junctions. Hence a blocking diode at the input is needed to withstand a steady state reverse battery condition. 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.



Current in reverse polarity (NPN bipolar regulator)

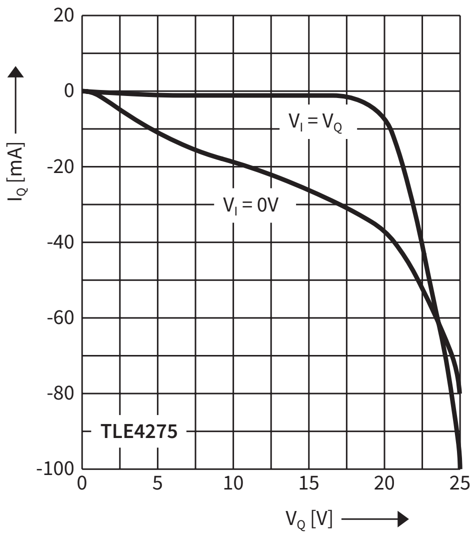
PNP bipolar voltage regulators and trackers (TLE4xxx except TLE4x8x)

Regulators with PNP pass transistors allow negative supply voltage. The reverse current is limited by the PNP transistor in reverse polarity conditions. Therefore a reverse protection diode at the input is not needed.

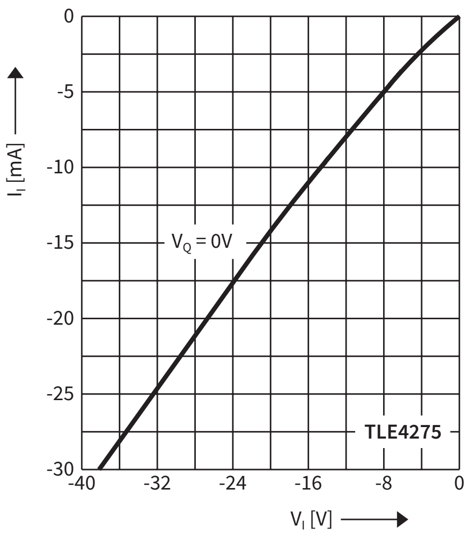


Current in reverse polarity (PNP bipolar regulator)

The typical reverse currents of bipolar PNP regulators are shown in the graphs below:



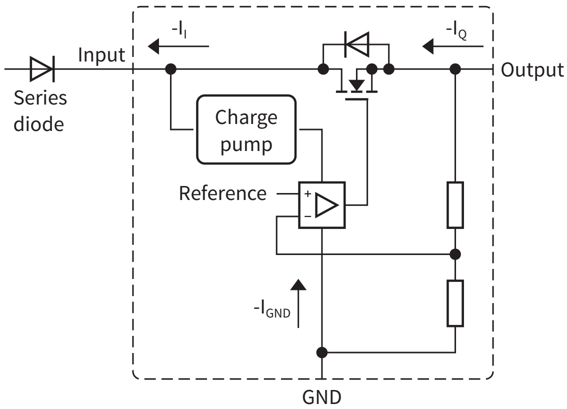
Typical reverse current (TLE4275)



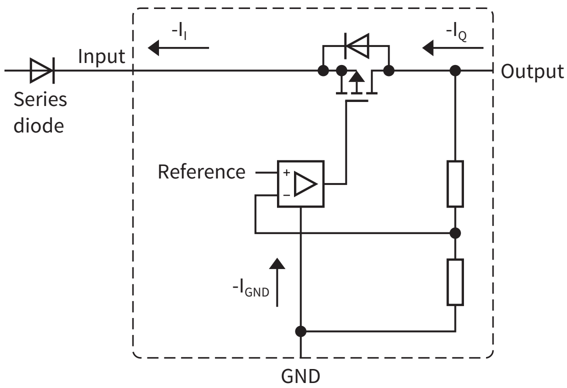
Typical reverse current (TLE4275)

The reverse voltage causes several small currents to flow into the IC, hence increasing its junction temperature. As thermal shutdown circuitry does not work in the reverse polarity condition, designers have to consider the temperature increase in their thermal design.

MOSFET voltage regulators (TLE7xxx and TLF80511)
Linear voltage regulators with a MOSFET (NMOS or PMOS) transistor as the pass element offer no reverse polarity protection. An unlimited reverse current would flow through the MOSFET's reverse diode. Therefore, a series diode at the IC input is mandatory. During normal operation, it will be forward biased, adding an additional drop voltage to the system. Therefore, a Schottky diode with a low forward voltage is recommended.

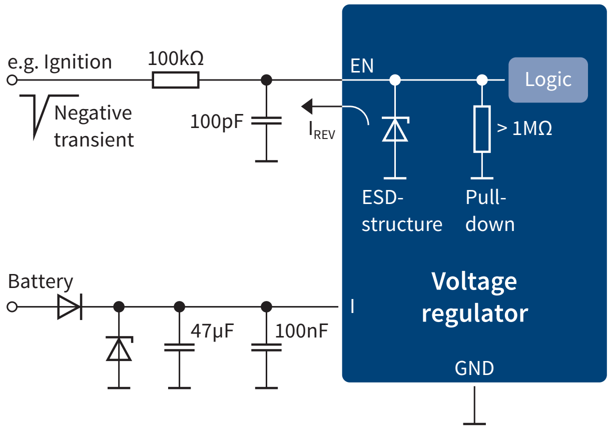


Current in reverse polarity (NMOS regulator)



Current in reverse polarity (PMOS regulator)

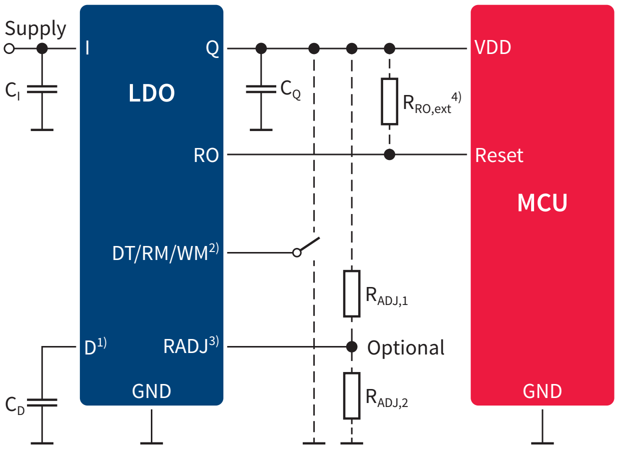
Regarding the Enable (Inhibit) pin, negative voltages must not be applied. Nevertheless, to allow negative transients to flow, a high-ohmic resistor can be added in series to protect the input structure. The maximum negative current must not exceed 0.5mA.



Negative transients at the inhibit pin of an NMOS regulator

Feature Description

Reset



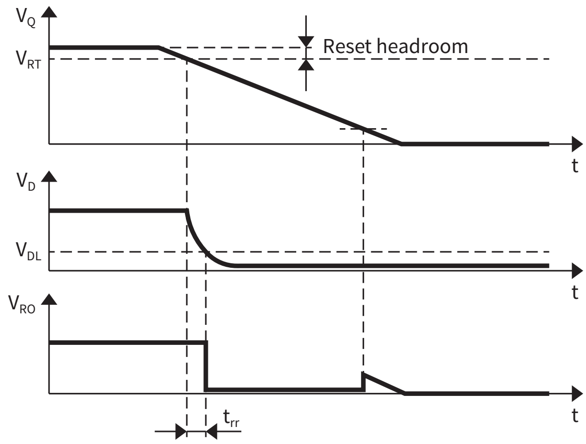
1) Only available for the voltage regulators with RESET function in TLE42xx series, TLE44xx series, TLE46xx series and TLF4949.
2) Only available for the voltage regulators with RESET function in TLE72xx series and TLE7469. The name of this pin can differ from device to device.
3) Not available for TLE4267, TLE4270-2, TLE4271-2, TLE42754, TLE4287, TLE4473, TLE4675 and TLE72xx series.
4) The external pull-up resistor is mandatory for TLE42754, TLE42794, TLE4290, TLE4473, TLE4675, as well as TLE72xx-2GV33/GV26 and TLE7469GV52/GV53, optional for all other voltage regulators with RESET function.

Reset application circuit

Devices with analog reset				
TLE4262	TLE42694/-2	TLE42794	TLE4471	TLE4699
TLE4263/-2	TLE4270-2	TLE4287	TLE4473	TLF4949
TLE4267/-2	TLE42754	TLE4291	TLE4675	
TLE4268	TLE4278	TLE42994	TLE4678	
Devices with digital reset				
TLE7270-2	TLE7273-2	TLE7279-2		
TLE7272-2	TLE7278-2	TLE7469		
Power good				
TLE4285	TLE4290	TLE4295		

Output undervoltage reset

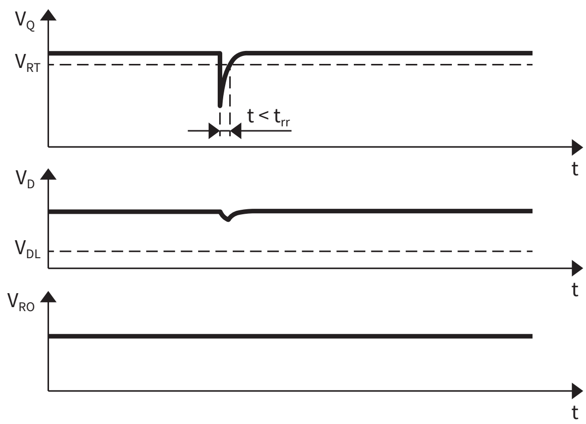
The output undervoltage reset operates by sensing the output voltage V_{OUT} and comparing it to an internal reset threshold voltage V_{RT}. If the output voltage drops below the reset threshold, the reset output is active low as long as the low output state exists. The reset output is typically connected to a microcontroller's reset pin as shown in the application circuit.



Output undervoltage reset

Reset reaction time

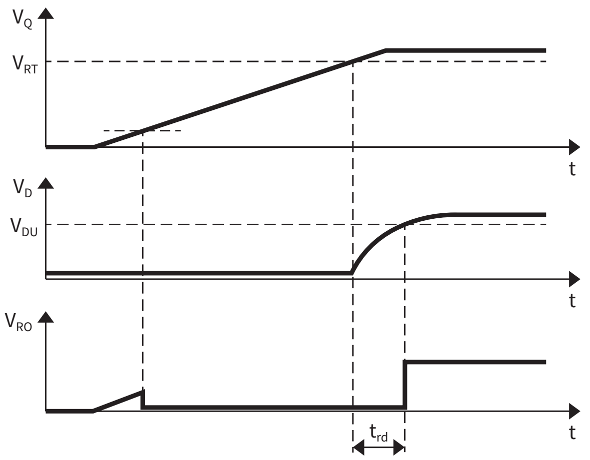
Short negative voltage spikes should not trigger an output undervoltage reset. The undervoltage reset should only be generated when the output voltage is below the reset threshold for longer than the predefined reset reaction time t_{rr}.



Reset reaction time

Power-on reset delay

Most control modules have a microcontroller and an accompanying clock oscillator. When the module is turned on, the clock oscillator requires a period of typically 1 to 10ms to reach a stable frequency. If the microcontroller begins operating before the oscillator is stable, the microcontroller may not initialize correctly. The power-on reset delay prevents a microcontroller from initializing while the oscillator is still stabilizing.



Power-on reset delay

How to adjust reset timing?

Analog reset timing

For the Infineon TLE4xxx series and TLF4949 linear voltage regulators, the power-on reset delay time t_{rd} and the reset reaction time t_{rr} are determined by the delay capacitor C_D connected to the D pin (see application circuit).

In datasheets, the reset timing is given for a certain capacitor, e.g. 100nF.

Example: TLE4291 reset timing

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Power-on reset delay time	$t_{d,PWR,ON}$	8	13.5	18	ms	Calculated value; C_D = 100nF
Internal reset reaction time	$t_{rr,int}$	–	9.0	15	µs	C_D = 0nF
Delay capacitor discharge time	$t_{rr,d}$	–	1.9	3	µs	C_D = 100nF
Total reset reaction time	$t_{rr,total}$	–	11.0	18	µs	Calculated value; $t_{rr,d,100nF} + t_{rr,int}$; C_D = 100nF

In case a power-on reset delay time t_{rd} different from the value specified at C_D = 100nF is required, the corresponding value of the delay capacitor can be calculated as follows:

$$C_D = \frac{t_{rd}}{t_{rd,100nF}} \times 100nF$$

Correspondingly, the reset reaction time trr can be calculated with the formula:

$$t_{rr} = \frac{C_D}{100nF} \times t_{rr,d,100nF} + t_{rr,int}$$

Digital reset timing

For the Infineon TLE72xx series linear voltage regulators, the power-on reset delay time t_{rd} is selectable between two predefined values through the configuration at the reset timing selection pin DT/RM/WM (see application circuit).

Example: TLE7279-2 reset timing

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Power-on reset delay time	t_{rd}	12.8	16	19.2	ms	Fast reset timing RM = low
		25.6	32	38.4	ms	Slow reset timing RM = high

Power good/power fail

In some Infineon voltage regulators, the power good/power fail function is implemented. This functionality is similar to the reset function.

In TLE4290, output voltage is supervised through a power good circuit. This function is the same as an analog reset, including delay timing set by a delay capacitance as described above for analog reset timing.

In TLE4285 and TLE4295, output undervoltage is alerted by the power fail (PF) pin. As soon as VQ falls below its power fail switching threshold, its output PF is set to LOW. There is no delay pin available for connecting an external capacitor to set a reaction or delay time.

In the voltage tracker TLE4254, the power good function not only alerts the undervoltage, but also the overvoltage, providing an added safety feature.

Tips & tricks

Pull-up at reset output RO

The reset output RO is an open collector output requiring a pull-up resistor to a positive voltage rail (e.g. output voltage V_Q).

In some linear voltage regulators, RO output is internally pulled up to the output voltage. An external pull-up resistor to the output Q can be added, in case a lower-ohmic RO signal is desired. As the maximum RO sink current is limited, a minimum value of the external resistor $R_{RO,ext}$ is specified in the datasheet and must be adhered to.

Example:

TLE4291 RO internal and external pull-up resistors

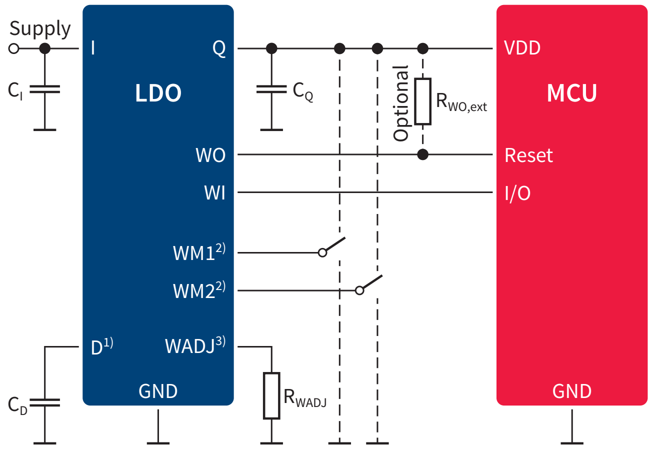
Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Reset output external pull-up resistor to Q	$R_{RO,ext}$	5.6	–	–	kΩ	$1V \le V_Q \le V_{RT,low}$; $V_{RO} = 0.4V$
Reset output internal pull-up resistor	R_{RO}	20.0	30	40	kΩ	Internally connected to Q

In some other regulators, there is no internal pull-up resistor at RO to the output voltage. For those regulators an external pull-up resistor is required. The minimum value of the required external pull-up resistor R_{RO} is given in the datasheet.

Example: TLE42754 RO external pull-up resistor

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Reset output external pull-up resistor to V_Q	R_{RO}	5	–	–	kΩ	$1V \le V_Q \le V_{RT}$; $V_{RO} = 0.4V$

Watchdog



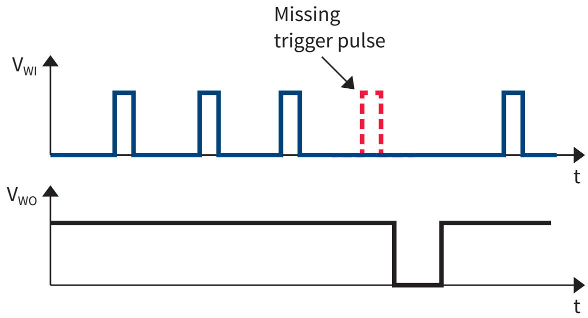
1) Only available for TLE4263-2, TLE4268, TLE4271-2, TLE4291, TLE4278, TLE4678, TLE4471, TLE4473
2) Only available for TLE7273-2, TLE7278-2, TLE7469
3) Only available for TLE4278, TLE4678

Watchdog application circuit

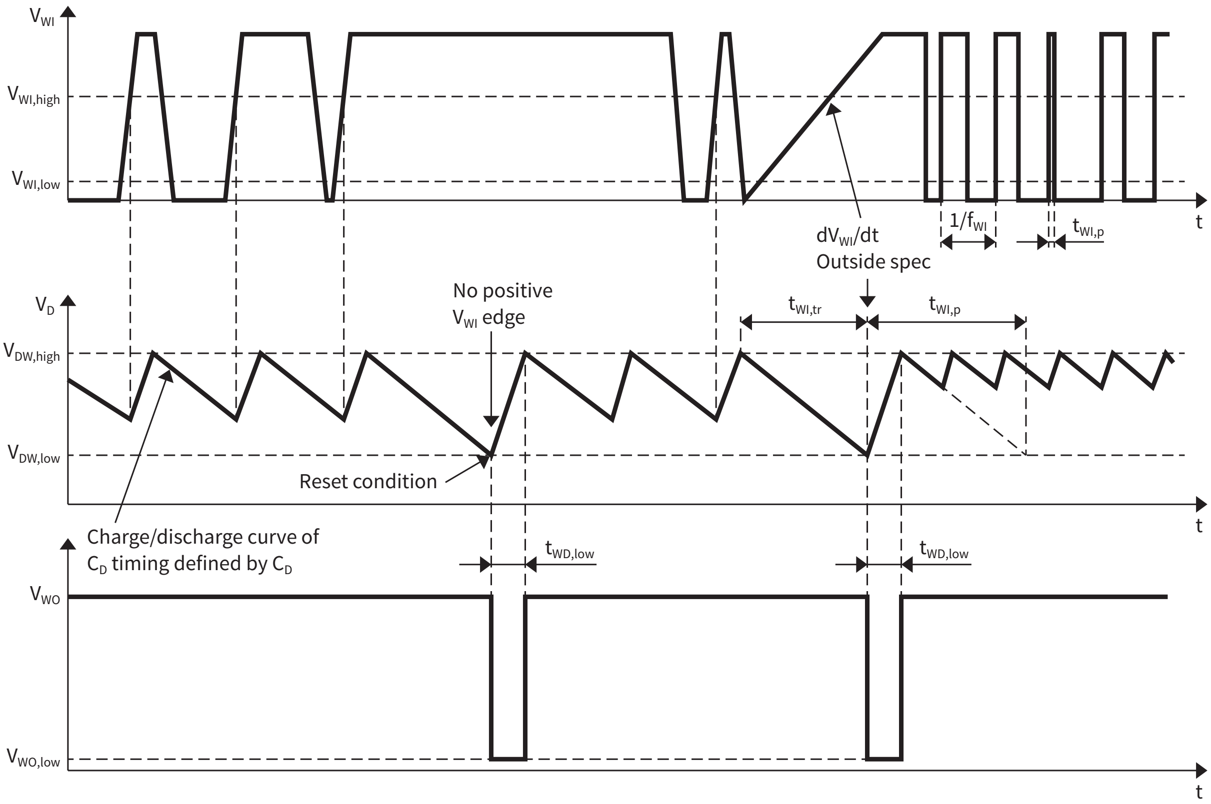
Devices with standard watchdog			
TLE4263/-2 TLE4268	TLE4278 TLE4291	TLE4471 TLE4473	TLE4678 TLE7278-2
Devices with window watchdog			
TLE7273-2	TLE7469		

Why do we need a watchdog?

The watchdog monitors the microcontroller to ensure it is operating normally. The function of the watchdog timer is to monitor the timing of the microcontroller and reset it to a known state of operation in case of an obvious timing error. For example, a microcontroller could get stuck in a software loop and stop responding to other inputs. If too much time elapses between triggers, the watchdog senses that something is wrong and sends a reset signal to the microcontroller.



Standard watchdog



Watchdog timing (analog implementation)

Watchdog timing – analog implementation[1)]

Positive edges at the watchdog input pin “WI” are expected within the watchdog trigger timeframe $t_{WI,tr}$, otherwise a low signal at pin “WO” is generated and it remains low for $t_{WD,low}$. All watchdog timings are defined by charging and discharging capacitor C_D at pin “D”. Thus, the watchdog timing can be programmed by selecting C_D.

In the datasheet, reset timing is given for a certain capacitor, e.g. 100nF.

1) Applicable to TLE4263-2, TLE4268, TLE4271-2, TLE4291, TLE4278, TLE4678, TLE4471, TLE4473

Example: TLE4678 watchdog timing

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Watchdog trigger time	$t_{WI,tr,100nF}$	25	36	47	ms	Calculated value; C_D = 100nF
Watchdog output low time	$t_{WD,low,100nF}$	13	18	23	ms	Calculated value; C_D = 100nF $V_Q > V_{RT,low}$
Watchdog period	$t_{WD,p,100nF}$	38	54	70	ms	Calculated value; $t_{WI,tr,100nF} + t_{WD,low,100nF}$ C_D = 100nF

In case a watchdog trigger time period $t_{WI,tr}$ different from the value specified at C_D = 100nF is required, the corresponding value of the delay capacitor value can be derived as follows:

$$C_D = 100nF \times \frac{t_{WI,tr}}{t_{WI,tr,100nF}}$$

Watchdog output low time $t_{WD,low}$ and watchdog period $t_{WD,p}$ can be derived using:

$$t_{WD,low} = t_{WD,low,100nF} \times \frac{C_D}{100nF}$$

$$t_{WD,p} = t_{WI,tr} + t_{WD,low}$$

Watchdog timing – digital implementation [1]

WM1	L	L	H	H
WM2	L	H	L	H
Watchdog mode	Fast	Slow	Fast	Off
Reset mode	Fast	Slow	Slow	Slow

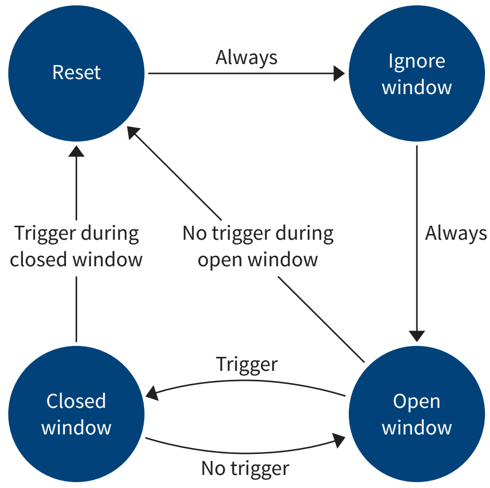
The watchdog uses an internal oscillator as its time base. The watchdog time base can be adjusted using the pins WM1 and WM2.

Example: TLE7273-2 watchdog timing

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Ignore window time	t_{OW}	25.6	32	38.4	ms	Fast watchdog timing
		51.2	64	76.8	ms	Slow watchdog timing
Watchdog period	$t_{WD,p}$	25.6	32	38.4	ms	Fast watchdog timing
		51.2	64	76.8	ms	Slow watchdog timing

Window watchdog [2]

For safety-critical applications a more advanced watchdog called window watchdog is provided for higher security of the system. The window watchdog operates in a similar manner to the standard watchdog except a trigger must occur within a certain window or time slot. If a trigger occurs outside of the window or does not occur at all within the designated window, the window watchdog will reset the microcontroller. When an unintentional trigger occurs, the standard watchdog is not able to decipher if this trigger is valid. The window requirement enables the window watchdog to detect unintentional triggers.



Window watchdog

Load-dependent watchdog activation

If a microcontroller is set to sleep mode or to low power mode, its current consumption is very low and it might not be able to send any watchdog pulses to the voltage regulator's watchdog input "WI". In order to avoid unwanted wake-up signals due to missing edges at pin "WI", the watchdog function of some linear voltage regulators can be activated dependent on the regulator's output current.

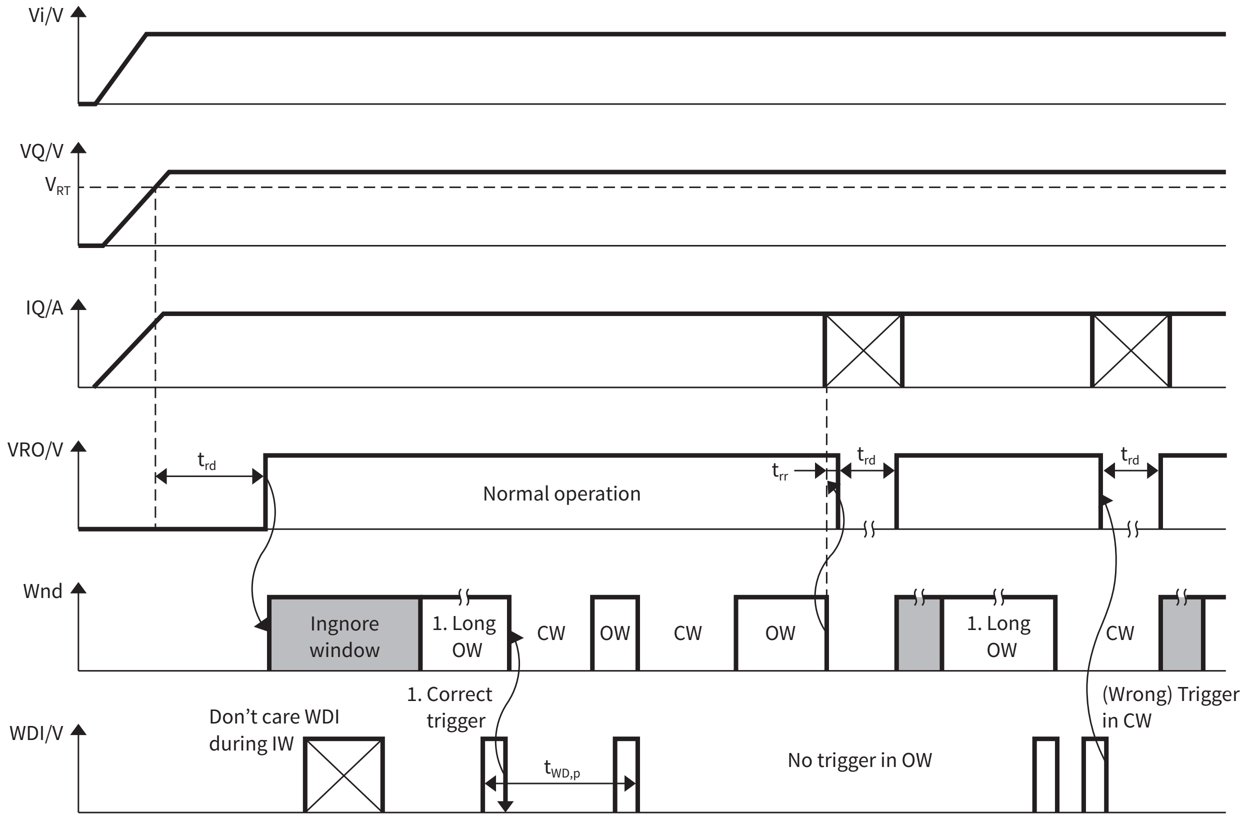
The load-dependent watchdog activation feature is available on TLE4268, TLE4278, TLE4678, TLE7273-2 and TLE7278-2.

On voltage regulators TLE4268, TLE7273-2 and TLE7278-2, watchdog activation and deactivation thresholds are fixed.

On voltage regulators TLE4278 and TLE4678, the watchdog can be permanently activated or deactivated, or enabled/disabled by defining a current threshold through the external resistor at the WADJ pin:

- An external resistor at WADJ to GND determines the watchdog activation threshold.
- Connect WADJ directly to GND to permanently deactivate the watchdog.
- Connect WADJ to the output Q via a 270kΩ resistor to permanently activate the watchdog.

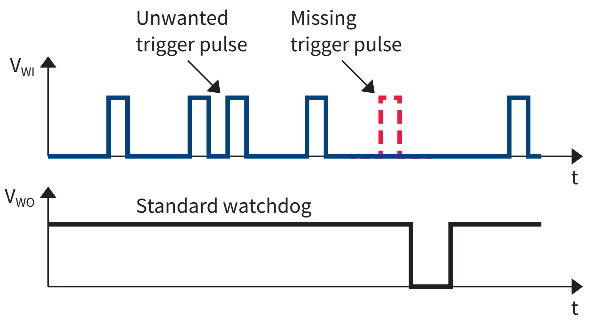
1) Applicable to TLE7273-2, TLE7278-2, TLE7469
2) The window watchdog is available for voltage regulators TLE7273-2 and TLE7469.



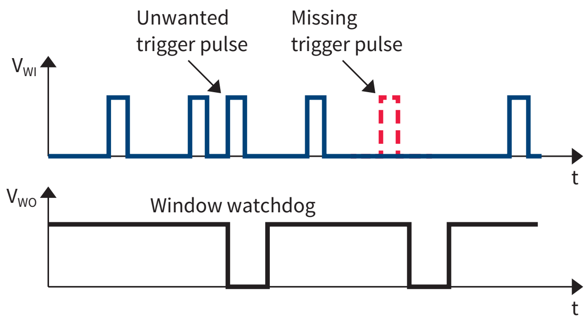
Watchdog timing (window watchdog)

Disadvantage of a standard watchdog
It is possible that the microcontroller could become trapped in a routine of only emitting the pulses. The standard watchdog is not capable of detecting this potential program error and would interpret this signal as valid. The solution in this case would be to use the window watchdog.

Window watchdog
To further reduce the potential risk of program errors, a more advanced watchdog called window watchdog has been implemented. It offers higher system security. A window watchdog monitors not only the minimum pulse period, but also the maximum pulse period. A watchdog pulse must occur within a certain window or time slot. If a pulse occurs outside of the window or does not occur at all within the designated window, the window watchdog will reset the microcontroller.



Disadvantage of standard watchdog



Advantage of window watchdog

Tips & tricks

Watchdog deactivation

In some applications, the microcontroller software is stored in an external non-volatile memory and needs to be downloaded to the microcontroller after every start-up. During this download, the microcontroller is not able to send any watchdog pulses. To skip unwanted watchdog alerts due to missing WI-input edges, the watchdog function should be deactivated.

The watchdog function can be easily deactivated by connecting WADJ directly to GND for those regulators with an adjustable watchdog activation threshold (TLE4278 and TLE4678).

For other linear regulators, the watchdog function could be deactivated by connecting the D pin to the output Q via a pull-up resistor to compensate the discharge current of the watchdog. The pull-up resistor can be determined by referring to the delay capacitor discharge current specified in the datasheet.

Example: watchdog deactivation for TLE4263-2

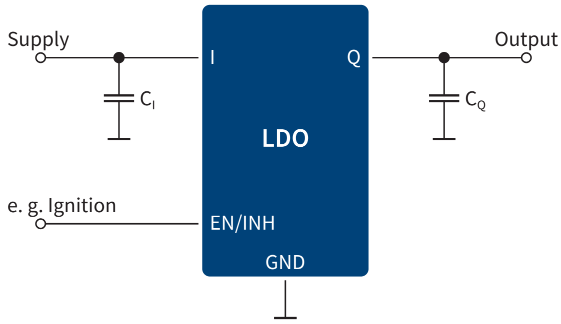
Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Discharge current	$I_{D,wd}$	4.40	6.25	9.40	µA	$V_D = 1.0V$

Formula to apply:

$R_{PU,D} \le (V_Q - V_D)/I_{D,wd,max} = (5.0V - 1.0V)/9.40µA = 425kΩ$

Taking some headroom for tolerances, a 390kΩ pull-up resistor could be recommended for deactivating the watchdog function on the TLE4263-2.

Enable



Enable application circuit

Devices with enable			
TLE42364	TLE4276-2	TLE42994	TLE7273-2
TLE4262	TLE42764	TLE4471	TLE7276-2
TLE4263/-2	TLE4286	TLE4473	TLE7278-2
TLE4266-2	TLE4287	TLE4476	TLE7279-2
TLE42664	TLE4291	TLE4699	TLE7469
TLE4267/-2	TLE4296/-2	TLE7272-2	

Why do we need enable?

Many linear voltage regulators can be turned off with an enable control input. In some automotive and battery-run applications, it is necessary to significantly reduce the quiescent current when the module is off. This can be accomplished by turning off the linear voltage regulator with low-logic signal (0V) applied to the EN pin. To turn on the regulator again, a high-logic signal (e.g. 5V) is applied to the EN pin.

This function is also called inhibit and the corresponding pin is called INH in some older voltage regulators.

If the enable/inhibit function is not used, the EN or INH pin must be connected to the input I.

Example: TLE42994 current consumption

$V_I = 13.5V$; $T_j = -40°C < T_j < 150°C$

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Current consumption; $I_q = I_I - I_Q$	I_q	–	65	105[1]	µA	Enable HIGH[1]; $I_Q \le 1mA$[1]; $T_j < 85°C$
Current consumption; $I_q = I_I - I_Q$	I_q	–	–	1[2]	µA	$V_{EN} = 0V$[2]; $T_j = 25°C$

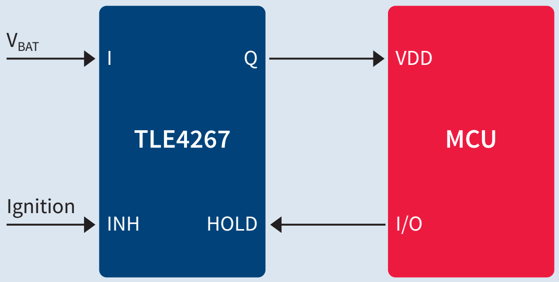
1) Though no output current is flowing, the regulator is still supplying the nominal output voltage and consumes some current.

2) The output voltage is switched off by EN/INH, the regulator consumes only very low stand-by current.

Tips & tricks

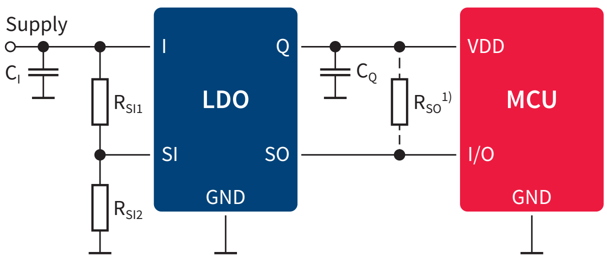
TLE4267 inhibit/hold function

In microcontroller supply systems, enable/inhibit might be controlled by the ignition key. Microcontrollers must be able to store data in case the ignition key is turned off. The additional HOLD pin of the TLE4267 allows microcontrollers to control the turn-off sequence. The voltage regulator remains on after inhibit is turned off as long as the microcontroller keeps the HOLD pin active low. The microcontroller can then release the HOLD signal when it is ready to be switched off, and then the voltage regulator will be turned off.



TLE4267 inhibit/hold function

Early warning



1) The external pull-up resistor is mandatory for TLE42794, TLE72xx-2GV33/GV26 and TLE7469GV52/GV53, optional for all other voltage regulators with Early Warning function.

Early warning application circuit

Devices with early warning		
TLE42694	TLE4699	TLE7279-2
TLE42994	TLE7469	TLF4949

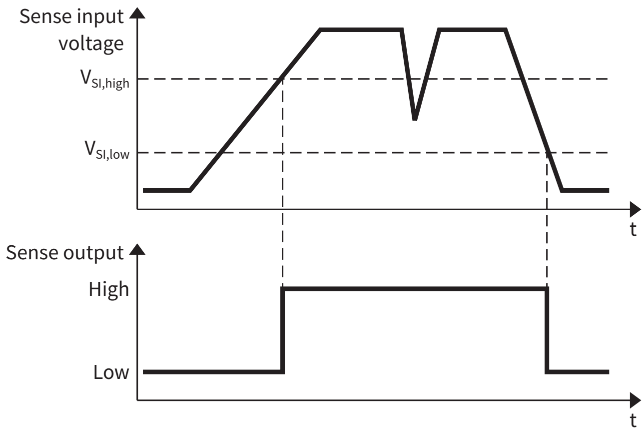
Why do we need early warning?

The purpose of the early warning function is to alert the microcontroller that the supply voltage is dropping and a reset signal is imminent. This allows the microcontroller to perform any “house cleaning” chores like saving RAM values into EEPROM memory so it can resume operation at its start-up state when it powers up again and the reset is released.

The early warning function is generally an integrated and independent comparator with a status output, which can compare any external voltage with the internal reference voltage. Besides the input voltage, this function can be used to sense any voltage rail on the board, sending a high/low status signal to a logic-IC or a microcontroller. For this reason, this function is also called the sense function.

Early warning function

The early warning function monitors the input voltage by comparing a divided sample of the input voltage to a known reference voltage. When the voltage at the sense input (SI) V_{SI} drops below the sense low threshold $V_{SI,low}$ an active low warning signal is generated at the sense output (SO) pin.



Early warning function

The desired threshold voltage for the input voltage is adjustable through the external voltage divider:

$$V_{I,TH} = V_{SI} \times \left(\frac{R_{SI1} + R_{SI2}}{R_{SI2}} \right)$$

$V_{I,TH}$: desired threshold triggering the early warning.
V_{SI}: given in the datasheet by $V_{SI,low}$ and $V_{SI,high}$.

Example: TLE42694 early warning thresholds

Parameter	Symbol	Limit values			Unit
		Min.	Typ.	Max.	
Sense threshold high	$V_{SI,high}$	1.24	1.31	1.38	V
Sense threshold low	$V_{SI,low}$	1.16	1.22	1.28	V
Sense switching hysteresis	$V_{SI,hy}$	20	90	160	mV

Application Details

Thermal considerations

The maximum junction temperature allowed for most Infineon automotive linear voltage regulators is 150°C. The thermal shutdown protection can prevent the device from direct damage caused by an excessively high junction temperature. Moreover, exceeding the specified maximum junction temperature reduces the lifetime of the device. A proper design must ensure that the linear regulator is always working beneath the allowed maximum junction temperature as specified in the datasheet of the device.

Thermal resistance

Thermal resistance is the temperature difference across a structure in the presence of a unit of power dissipation. It reflects to the capacity of the package to conduct heat outside the device. It is the key parameter to be considered in the thermal design. The most useful thermal resistance for thermal calculation is the junction-to-ambient thermal resistance R_{thJA}. In most datasheets, junction-to-ambient thermal resistance R_{thJA} is specified in accordance with JEDEC JESD51 standards defining PCB types and heat sink area.

Cross section JEDEC 1s0p board

Cross section JEDEC 2s2p board

Thermal calculation

Knowing the input voltage, the output voltage and the load profile of the application, the total power dissipation can be calculated:

$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} + V_{IN} \times I_q$

The maximum an acceptable thermal resistance R_{thJA} can then be calculated:

$R_{thJA,max} = (T_{j,max} - T_a)/P_D$

Based on the above calculation the proper PCB type and the necessary heat sink area can be selected with reference to the thermal resistance table in the regulator's datasheet. Below is an example of the thermal consideration for an application with TLE42754G.

Example: TLE42754G thermal resistance

Parameter	Symbol	Limit values			Unit	Conditions
		Min.	Typ.	Max.		
Junction to case[1]	R_{thJC}	–	3.7	–	k/W	–
Junction to ambient	R_{thJA}	–	22.0	–	k/W	[2]
		–	70.0	–	k/W	Footprint only[3]
		–	42.0	–	k/W	300mm² heatsink area on PCB[3]
		–	33.0	–	k/W	600mm² heatsink area on PCB[3]

1) Not subject to production test, specified by design.
2) Specified R_{thJA} value is according to Jedec JESD51-2, -5, -7 at natural convection on FR4 2s2p board; The product (chip + package) was simulated on a 76.2 x 114.3 x 1.5 mm³ board with 2 inner copper layers (2 x 70µm Cu, 2 x 35µm Cu). Where applicable a thermal via array under the exposed pad contacted the first inner copper layer.
3) Specified R_{thJA} value is according to JEDEC JESD 51-3 at natural convection on FR4 1s0p board; The product (chip + package) was simulated on a 76.2 x 114.3 x 1.5 mm³ board with 1 copper layer (1 x 70µm Cu).

Example: Thermal calculation for TLE42754G

Application conditions:

V_{IN} = 13.5V
V_{OUT} = 5V
I_{OUT} = 200mA
T_a = 85°C

Determination of R_{thJA}:

$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} + V_{IN} \times I_q$
$= (13.5V - 5V) \times 250mA + 13.5V \times 10mA$
$= 2.125W + 0.135W = 2.26W$

$R_{thJA,max} = (T_{j,max} - T_a)/P_D = (150°C - 85°C)/2.26W = 28.76K/W$

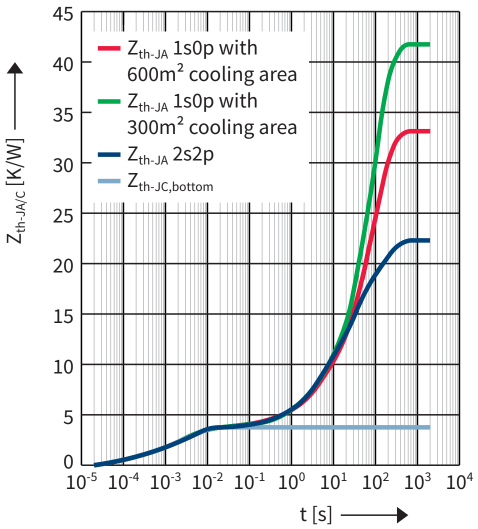
As a result, the PCB design must ensure a thermal resistance R_{thJA} lower than 28.76K/W. Referring to the thermal resistance table of the TLE42754G, only a FR4 2s2p board could be used.

Transient thermal resistance

Thermal resistance constant R_{thJA} reflects the steady-state condition of the power dissipation. In other words, the amount of heat generated in the junction of the device equals the heat conducted away. In some applications, the worst case conditions for power dissipation occur during the transient state. The duration in transient could be far shorter than steady-state.

Thermal impedance curves characterize delta temperature rise (between junction and ambient) versus power dissipation as a function of time. In this case, the junction temperature will be a function of time:

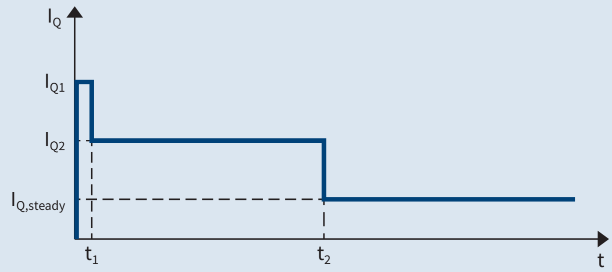
$T_j(t) = Z_{thJA}(t) \times P_D(t) + T_a$



Thermal impedance curve of TLE42754 in PG-TO263 package

Tips & tricks

Calculation example in transient based on TLE42754G. The following load current profile is applied.



Application conditions:		Load current:	
V_{IN}	= 13.5V	I_{Q1}	= 400mA
V_{OUT}	= 5V	I_{Q2}	= 250mA
T_a	= 85°C	$I_{Q,steady}$	= 100mA
PCB:	JEDEC 2s2p	t_1	= 10ms
		t_2	= 10s

Determination of junction temperature T_j:

$P_1 = (V_I - V_Q) \times I_{Q1} + V_I \times I_{q1}$
$= (13.5V - 5V) \times 400mA + 13.5V \times 25mA$
$= 3.74W$

$T_{j,t1} = T_a + P_1 \times R_{thJA,10ms}$
$= 85°C + 3.5K/W \times 3.74W = 85°C + 13.1°C$
$= 98.1°C <$ **150°C**

$P_2 = (V_I - V_Q) \times I_{Q2} + V_I \times I_{q2}$
$= (13.5V - 5V) \times 250mA + 13.5V \times 10mA$
$= 2.26W$

$T_{j,t2} = T_a + P_2 \times R_{thJA,10s}$
$= 85°C + 10.5K/W \times 2.26W$
$= 108.7°C <$ **150°C**

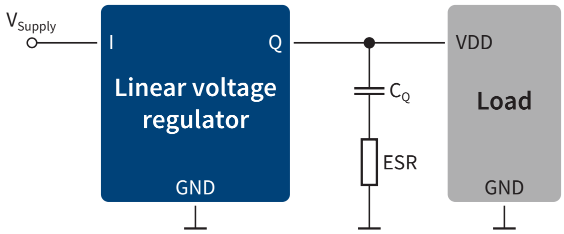
$P_{steady} = (V_I - V_Q) \times I_{Q,steady} + V_I \times I_{q,steady}$
$= (13.5V - 5V) \times 100mA + 13.5V \times 1.5mA$
$= 0.87W$

$T_{j,steady} = T_a + P_{steady} \times R_{thJA}$
$= 85°C + 22K/W \times 0.87W$
$= 104.1°C <$ **150°C**

The calculation result shows that the junction temperature of TLE42754G never exceeds the maximum threshold of 150°C. This is a valid thermal design.

Choice of output capacitance

An output capacitor is mandatory for the stability of linear voltage regulators. A linear voltage regulator can be described as a simple control system and the output capacitor is a part of the control system. Like all control systems, the linear voltage regulator has regions of instability. These regions depend to a great extent on two parameters of the system: the capacitance value of the output capacitor and its equivalent serial resistance ESR.



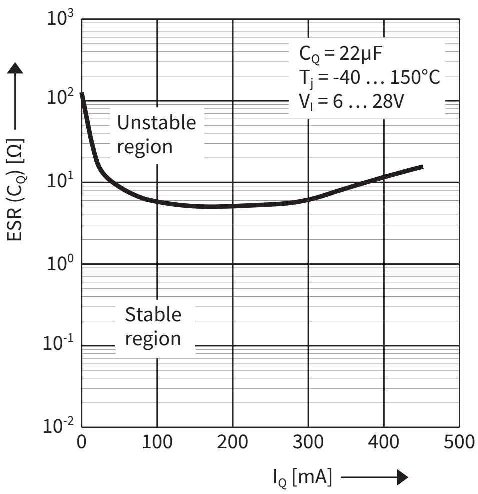
Application diagram

The requirement for the output capacitor is specified in the datasheet of each linear voltage regulator.

Example: TLE42754 output capacitor requirements

Parameter	Symbol	Limit values		Unit	Conditions
		Min.	Max.		
Output capacitor's requirements for stability	C_Q	22	–	µF	The minimum output capacitance requirement is applicable for a worst case capacitance tolerance of 30%
	ESR (C_Q)	–	3	Ω	Relevant ESR value at f = 10kHz

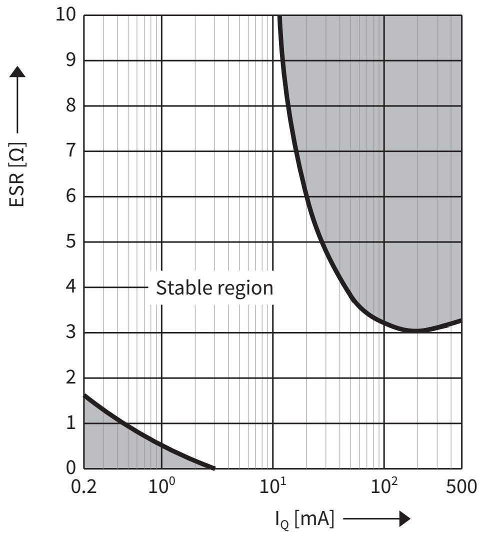
Typically an ESR versus output current plot can be found in the datasheet of Infineon voltage regulators showing the stability region.



Stability graph without minimum ESR requirement (TLE42754)

Most Infineon linear voltage regulators are designed to be stable with extremely low ESR capacitors. According to the automotive requirements, ceramic capacitors with X5R or X7R dielectrics are recommended.

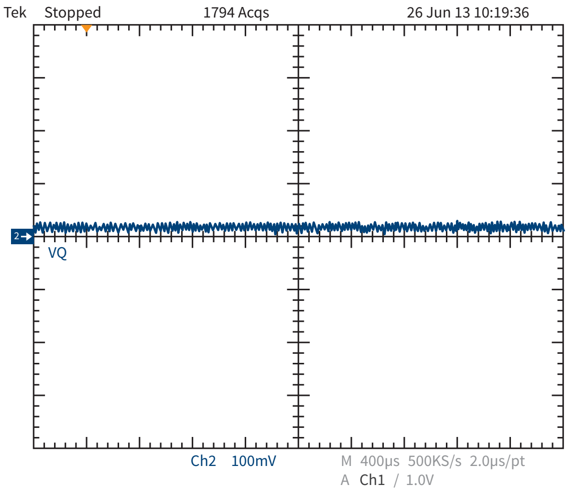
There are some older linear voltage regulators (see the list below) which require a small amount of ESR at the output capacitor for stability. Those regulators were designed some time ago when tantalum capacitors were widely used. So, it is recommended to connect an additional series resistor to the capacitor if a ceramic capacitor is used.



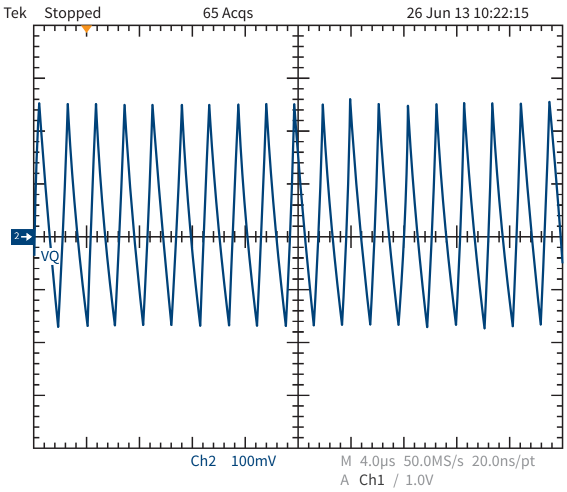
Stability graph with minimum ESR requirement (TLE4271-2)

Devices requiring small amount of ESR at C_Q				
TLE42344	TLE4268	TLE4278	TLE4294	TLE4471
TLE42364	TLE4270-2	TLE4285	TLE4295	TLF4476
TLE4263/-2	TLE4271-2	TLE4290	TLE4296	

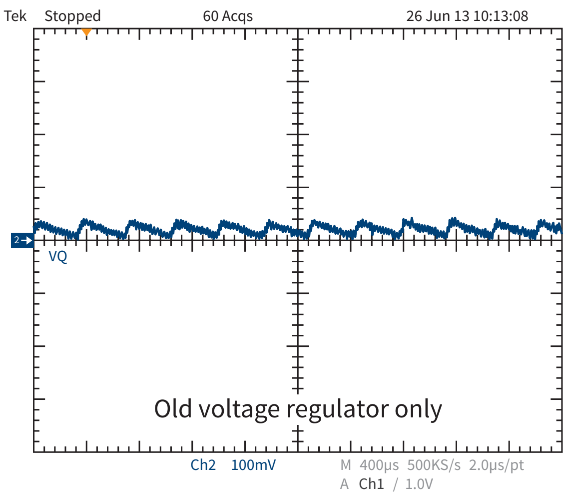
It is very important to comply with the requirements of the output capacitor as specified in the datasheet during selection. If the specified requirements are not fulfilled, the voltage regulator can be unstable and the output voltage can oscillate.



Stable output with C_Q and ESR (C_Q) according to the datasheet

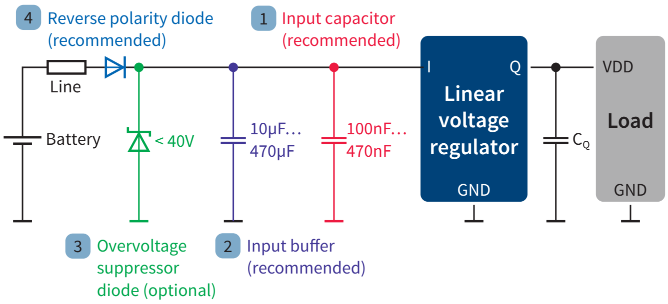


Oscillation with too high ESR (C_Q)



Oscillation with too low ESR (C_Q)

Design of input protection



Design of input protections

The figure above shows the typical input circuitry for a linear voltage regulator. Though input filtering is not mandatory for the stability of a linear regulator, some external devices and filtering circuits are recommended in order to protect the linear voltage regulator against external disturbances and damage.

1 A ceramic capacitor at the input in the range of 100nF to 470nF is recommended to filter out the high frequency disturbances imposed by the line, e.g. ISO pulses 3a/b. This capacitor must be placed very close to the input pin of the linear voltage regulator on the PCB.

2 An aluminum electrolytic capacitor in the range of 10µF to 470µF is recommended as an input buffer to smooth out high energy pulses, such as ISO pulse 2a. This capacitor should be placed close to the input pin of the linear voltage regulator on the PCB.

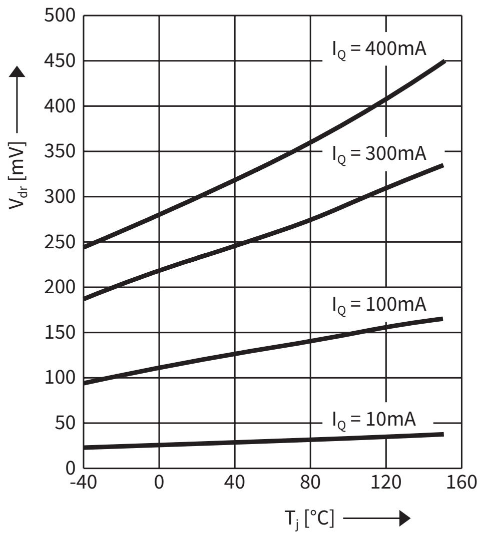
3 An overvoltage suppressor diode can be used to further suppress any high voltage beyond the maximum rating of the linear voltage regulator and protect the device against any damage due to overvoltage.

4 For linear voltage regulators with an NPN bipolar or a MOSFET power stage, a reverse polarity diode is mandatory to protect the device from damage due to reverse polarity. Though the regulators with a PNP power stage have internal reverse polarity protection, a reverse polarity diode is still recommended in order to avoid damage due to excessively high reverse voltage, e.g. the ISO pulse 1. The reverse polarity diode can be put anywhere on the module between the battery and the input pin of the regulator. It can also be shared with other elements on the module.

Drop-out voltage and tracking area

Drop-out voltage

Drop-out voltage is the minimum voltage differential between the input and output required for regulation. Regarding Infineon's datasheet definition, it is determined when output voltage has dropped 0.1V from its nominal value.



Typical drop-out voltage graphs (TLE42754)

Minimum input voltage

To regulate the output voltage at its nominal value, linear regulators require a minimum input voltage which is the nominal output voltage plus the maximum drop-out voltage ($V_{Q,nom} + V_{dr,max}$).

For example, consider a 5V regulator with a drop-out voltage of max. 0.5V. The minimum input voltage required for the 5V output is 5.5V.

In the datasheet this value is specified as the minimum value for the input voltage and can be found under functional range.

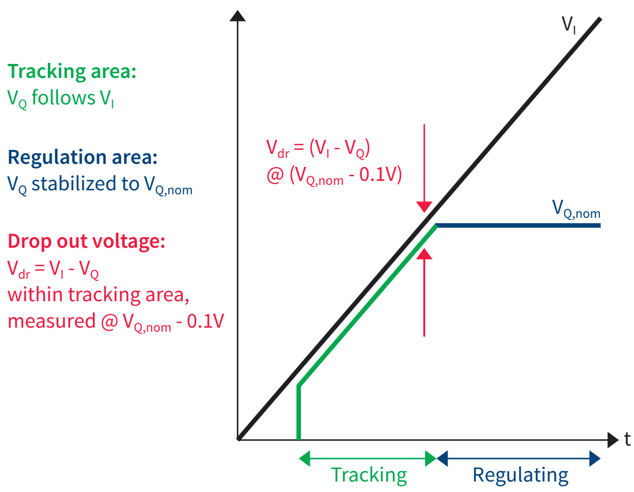
Example: TLE42754 input voltage range

Parameter	Symbol	Limit values		Unit	Conditions
		Min.	Max.		
Input voltage	V_I	5.5	42	V	–

Tracking area

When the input voltage is below the required minimum voltage, the linear regulator is not able to regulate the output voltage at its nominal value. However, as long as the input voltage is beyond a switching voltage threshold to turn the device off, the linear regulator is trying to maintain the output voltage. The output voltage is equal to $V_I - V_{dr}$. This input voltage range is known as the tracking area, since the output voltage is following the input.

The graph below illustrates the tracking and regulating area of a linear regulator while the input voltage rises slowly during the start-up.



Tracking area and drop-out voltage

Extended input voltage range

The newest Infineon linear voltage regulators start tracking at as low as 3.3V, which meets the requirement of cold cranking for automotive applications. The whole input voltage range, including the tracking area and the regulation area, is now specified as "Extended Input Voltage Range" in the datasheet.

Example: TLF80511 input voltage range

Parameter	Symbol	Limit values		Unit	Conditions
		Min.	Max.		
Input voltage range for normal operation	V_I	$V_{Q,nom} + V_{dr}$	40	V	–
Extended input voltage range	$V_{I,ext}$	3.3	40	V	1)

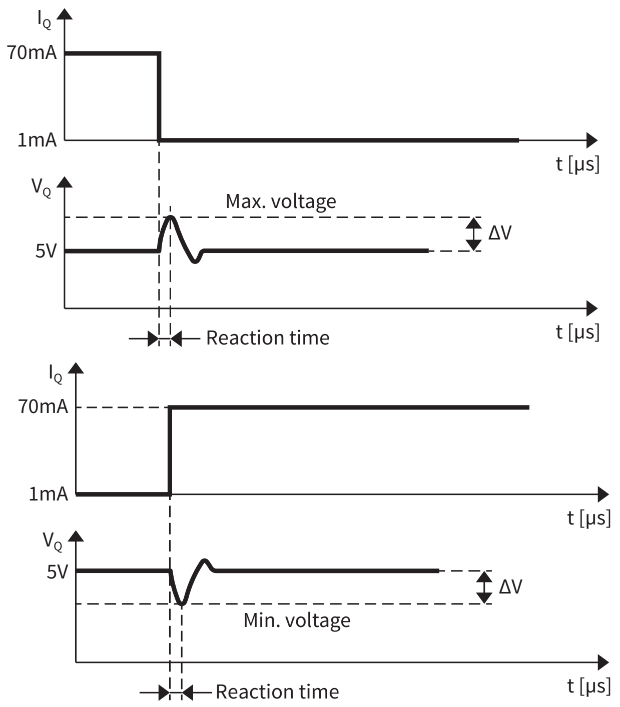
1) Between min. value and $V_{Q,nom} + V_{dr}$: $V_Q = V_I - V_{dr}$.
Below min. value: V_Q = 0V

Load transients

Every linear voltage regulator has an integrated control loop regulating output voltage. Different concepts of control loop can be implemented depending on the application. However, every regulation loop has a certain reaction time to adapt to load current variations. In a short period of time, the control loop is not able to react. It takes a minimum time for the voltage regulator to react and to set the output voltage back to its nominal value by adjusting the output current. In other words, voltage variations at the regulator's output are inevitable for a short time during current transient.

Typical application case: supply for a microcontroller
The current consumption of a microcontroller is usually less than 1mA in standby mode and from several 10mA up to a few 100mA in normal operating mode. In its application, the microcontroller is triggered from standby mode to normal operating mode or vice versa. A fast current transient is respectively rising or falling in 1μs at the voltage regulator's output.

The typical behavior of a linear voltage regulator at these current transients is shown in the figures below.



Output voltage deviation at load transient

Potential risks of big voltage variations are:

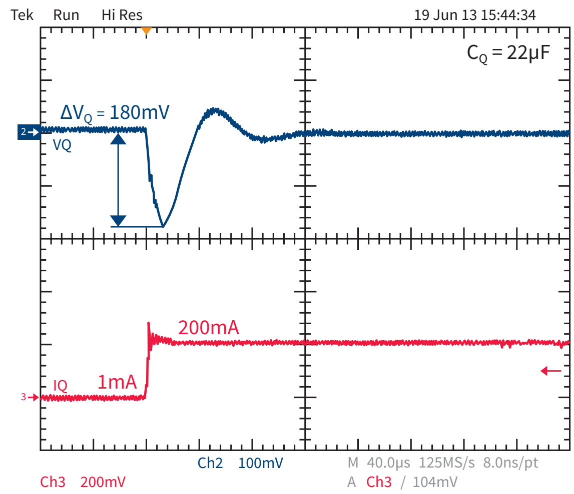
- Triggering an unwanted reset.
- Malfunction of the supplied microcontroller by exceeding its operating range.
- Damage of load by exceeding its maximum ratings.

To avoid big output voltage variations, basically two solutions are possible:

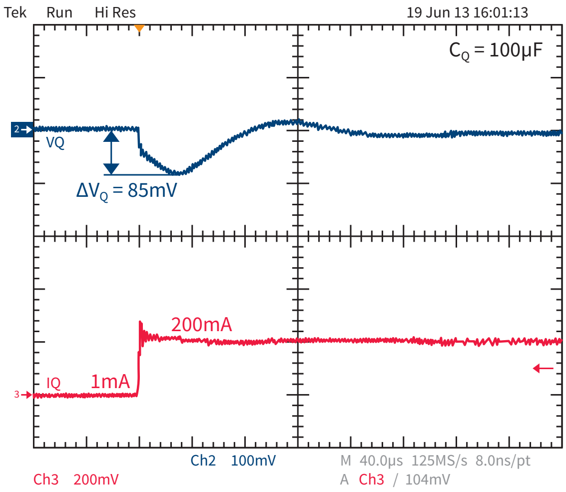
- Avoid big load current transients whenever possible. The designer should first of all try to avoid big current transients within the application.
- Increase the value of the output capacitor to buffer the voltage regulator's output voltage.

In case big load current transients are not avoidable, increasing the output capacitance can lower the voltage variations at load current transients and avoid the risks.

The following pictures show the output voltage deviation of the TLE42754 at a load current transient from 1mA to 200mA with 22μF and 100μF output capacitors. Whereas a voltage drop of 180mV has been recorded with a 22μF output capacitor, the drop is reduced to only 85mV with a 100μF output capacitor.



TLE42754 output voltage deviation at load transient with a 22μF output capacitor



TLE42754 output voltage deviation at load transient with a 100µF output capacitor

To dimension the output capacitor reasonably, the following steps are recommended:

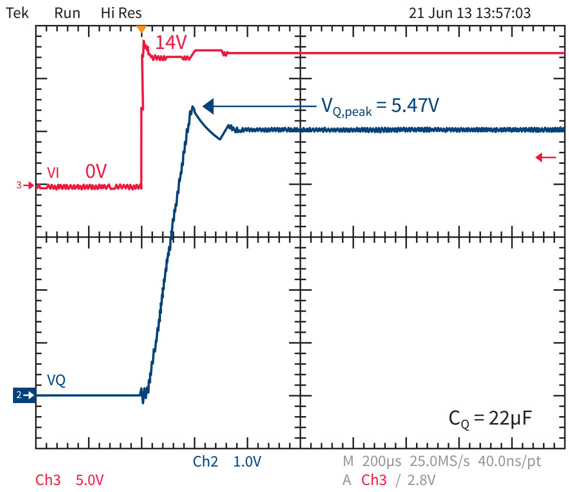
- Check for worst-case current transients within the application.
- Define max. allowed voltage variation ΔV_{max} during current transient.
- Determine the voltage variation ΔV of the voltage regulator at the worst-case current transient with the minimum output capacitance fulfilling the requirement for stability.
- If ΔV is higher than ΔV_{max}, try with a bigger output capacitance.
- Choose an output capacitor which ensures the voltage variation ΔV is within the allowed range.
- Verify the selected output capacitor on the application hardware.

Overshoot at start-up

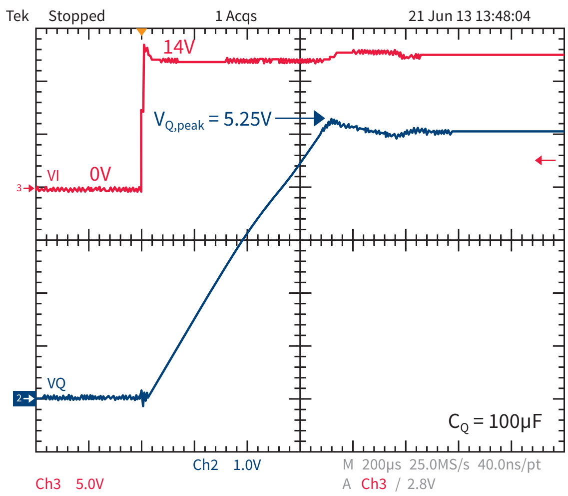
During the start-up, i.e. while the input voltage is powered on, the linear voltage regulator is driving the maximum output current to charge the output capacitor and raise the output voltage to the nominal value. When the nominal output voltage is reached, the control loop of the linear voltage regulator needs a few microseconds to react. During these few microseconds, the regulator is still charging the output cap, leading to a further increase of the output voltage. After those few microseconds, the regulator starts regulating the output voltage to the nominal voltage.

The overshoot level during the start-up is dependent on the load current and the output capacitor.

The effect of the output capacitor on the voltage overshoot is shown in the following graphs:



TLF42754 output voltage deviation at load transient with a 22µF output capacitor



TLF42754 output voltage deviation at load transient with a 100µF output capacitor

To smooth out voltage overshoot on start-up, two measures are recommended:

- Increase the capacitor value at the input to slow down the slope of the input voltage.
- Increase the output capacitor value to slow down the slope of the output voltage.

PCB layout

The PCB layout design is important for the performance of a linear voltage regulator. A good PCB layout can optimize the performance, whereas a poor one may impact on the stable operation of the regulator and introduce various disturbances in the system.

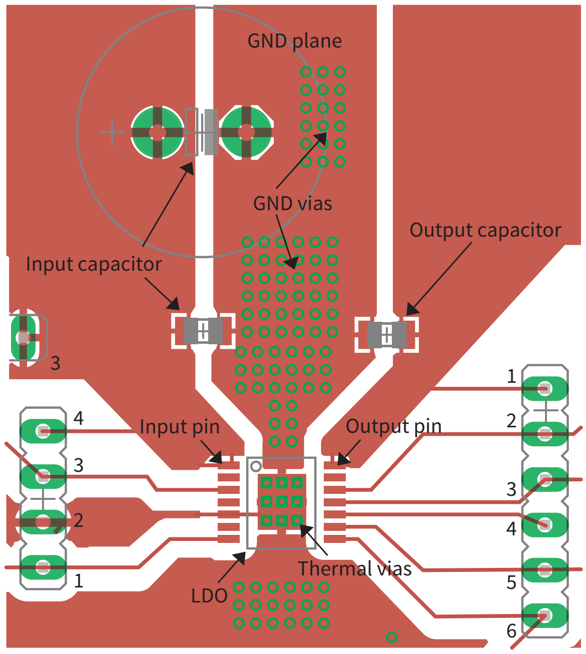
Here are some general recommendations for the PCB design with a linear voltage regulator:

- Place the output capacitor as close as possible to the regulator's output and GND pins and on the same side of the PCB as the regulator.
- Place the ceramic input capacitor (e.g. 100nF) as close as possible to the regulator's input pin and on the same side of the PCB as the regulator.
- Place the larger input buffer capacitor (e.g. 10µF) on the same PCB.
- Traces connected to the regulator's input and output should be sized according to the current flowing through it.
- Ensure a good GND connection.
- For 4 or more layer PCBs, use one middle layer for GND and place sufficient number of vias to GND layer.
- For a 1 or 2 layer PCB, place a sufficient GND plane.

The PCB layout design is also crucial to the thermal performance. Here are some recommendations for a good thermal design:

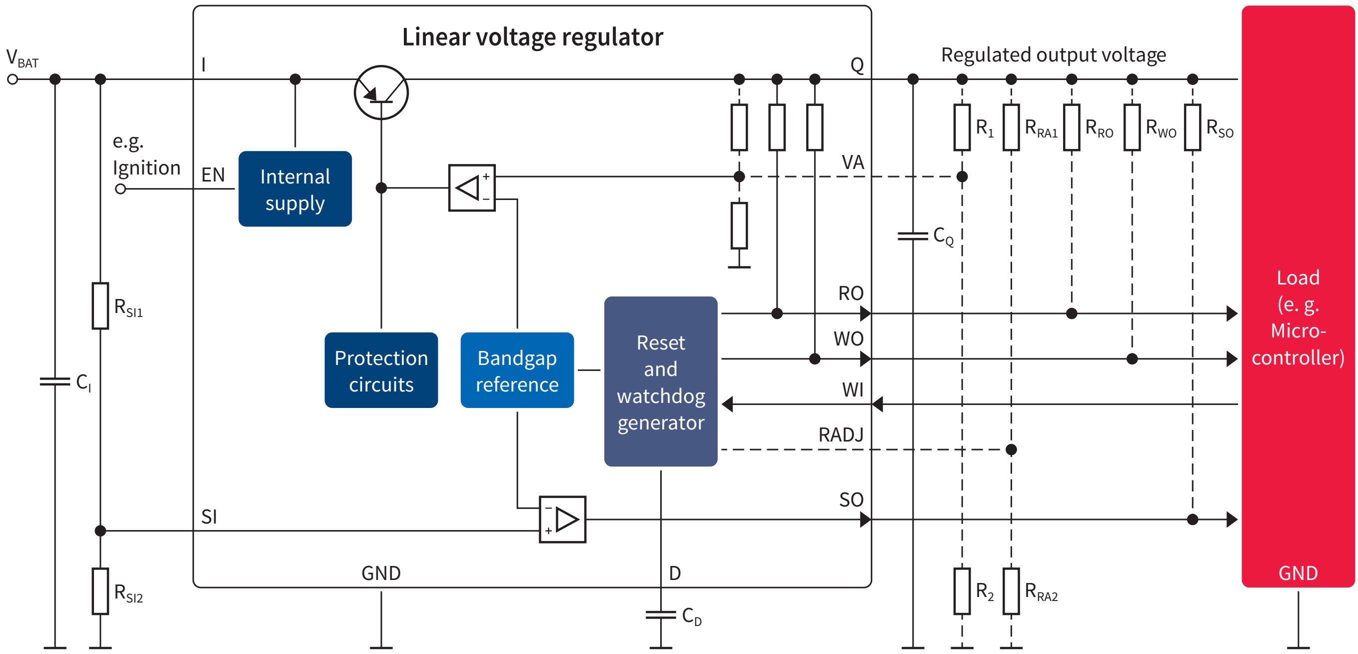
- Ensure good thermal connection.
- Place sufficient cooling area depending on the power dissipation.
- For 4 or more layer PCBs, place sufficient number of thermal vias to the thermal layer.
- Put other heat sources on the board as far away as possible from the position of the linear voltage regulator.

Below is an example of a good PCB layout design:

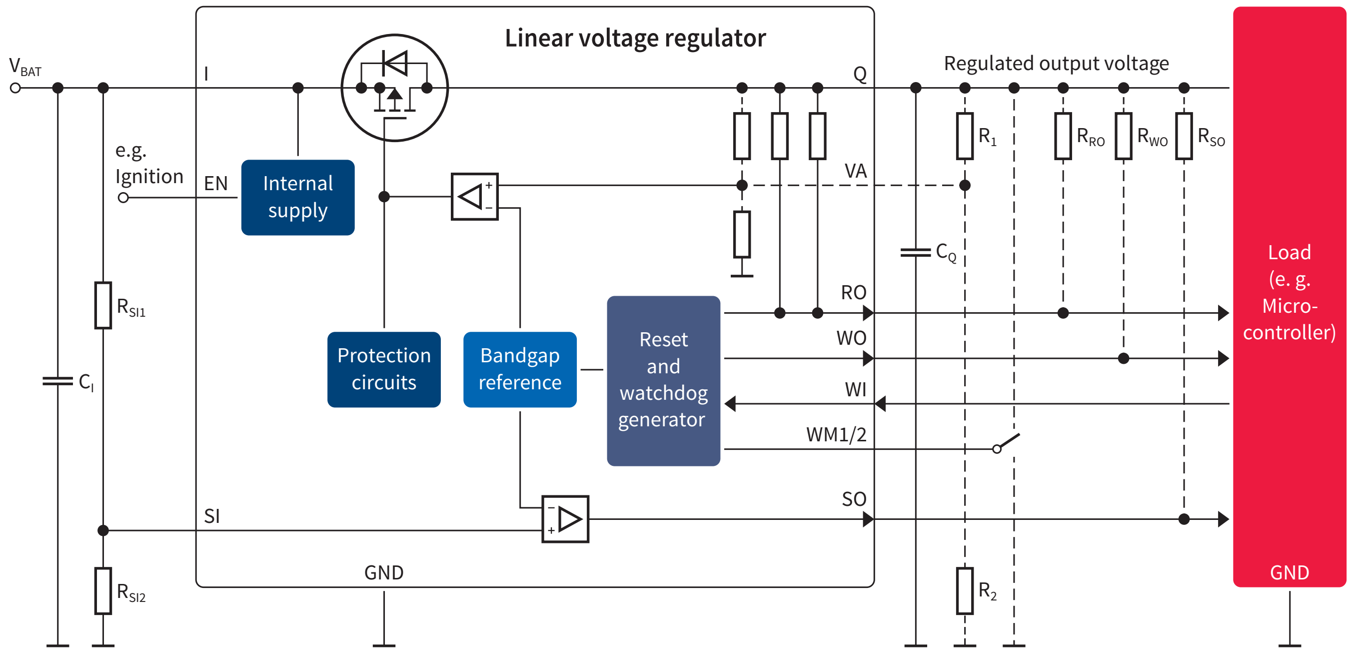


PCB layout example

Application Schematic



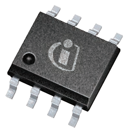
General application schematic for bipolar voltage regulators with analog reset and watchdog timing control



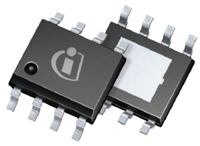
General application schematic for MOSFET voltage regulators with digital reset and watchdog timing control

Packages

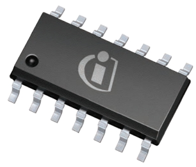
PG-DSO-8



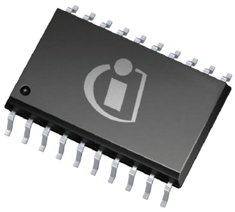
PG-DSO-8 (Exposed Pad)



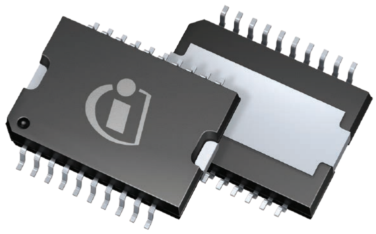
PG-DSO-14



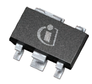
PG-DSO-20



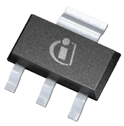
PG-DSO-20 (Power-SO)



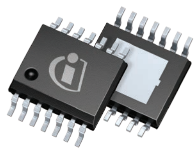
SCT595



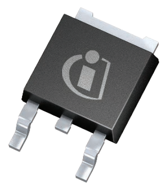
SOT223



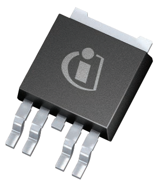
PG-SSOP-14EP



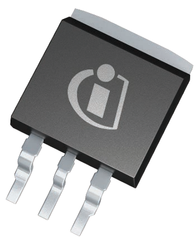
PG-TO252-3 (DPAK)



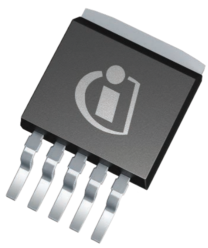
PG-TO252-5 (DPAK-5-leg)



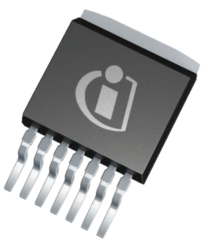
PG-TO263-3 (TO220-3 (SMD))



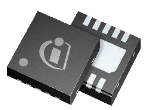
PG-TO263-5 (TO220-5 (SMD))



PG-TO263-7 (TO220-7 (SMD))



TSON-10



Glossary

ADJ	Adjustable output
C_D	Delay capacitor
C_I	Input capacitor
C_Q	Output capacitor
D	Delay capacitor pin for reset and watchdog
EN	Enable pin
ESR	Equivalent series resistance
I	Input pin
$I_{D,wd,max}$	Maximum watchdog discharge current
INH	Inhibit pin (ref. EN)
I_q	Quiescent current
$I_{Q,MAX}$	Maximum output current
$I_{q,steady}$	Steady state quiescent current
P_D	Power dissipation
P_{steady}	Steady state power
Q	Output pin
Q_{ADJ}	Adjustable output pin
R_1	Output voltage adjust resistor 1
R_2	Output voltage adjust resistor 2
RADJ	Reset threshold adjust pin
$R_{ADJ,1}$	Reset threshold adjust resistor 1
$R_{ADJ,2}$	Reset threshold adjust resistor 2
RO	Reset output pin
$R_{PU,D}$	Pull-up resistor at D pin for watchdog Deactivation
R_{RO}	Reset output internal pull-up resistor
$R_{RO,ext}$	Reset output external pull-up resistor
R_{SI1}	Sense input voltage divider resistor 1
R_{SI2}	Sense input voltage divider resistor 2
R_{thJA}	Junction to ambient thermal resistance
R_{thJC}	Junction case thermal resistance
$R_{WO,ext}$	Watchdog output external pull-up resistor
SI	Sense input pin
SO	Sense output pin
T_a	Ambient temperature
T_j	Junction temperature
$T_{j,max}$	Maximum junction temperature
$T_{j,sd}$	Thermal shutdown junction temperature
$T_{j,shd}$	Thermal shutdown junction temperature Hysteresis
$T_{j,steady}$	Steady state junction temperature
t_{rd}	Power-on reset delay time
$t_{rd,100nF}$	Power-on reset delay time with 100nF Capacitor
t_{rr}	Reset reaction time
$t_{rr,d,100nF}$	Reset reaction time delay with 100nF Capacitor
$t_{rr,int}$	Internal reset reaction time
$t_{STARTUP}$	Start-up time
$t_{WD,low}$	Low watchdog time
VA	Voltage adjust pin
V_{BAT}	Battery voltage
V_D	Voltage at D pin
VDD	Supply pin of microcontroller
V_{DL}	Delay capacitor lower threshold
V_{DU}	Delay capacitor upper threshold
V_I	Input voltage
$V_{I,TH}$	Threshold trigger the early warning
V_Q	Output voltage
$V_{Q,nom}$	Nominal output voltage
V_{ref}	Internal reference voltage
V_{RO}	Reset output voltage
V_{RT}	Reset threshold
V_{SI}	Sense input voltage
V_{WI}	Watchdog input voltage
V_{WO}	Watchdog output voltage
WI	Watchdog input pin
WM1	Watchdog mode Selection Pin 1
WM2	Watchdog mode Selection Pin 2
WO	Watchdog output
Z_{thJA}	Junction ambient thermal impedance

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