TLE7368 – Pre-regulator Filters Dimensioning

Multi Voltage Power Supply System

Z8F52274265

Application Note

Rev. 1.01, 2015-09-22

Automotive Power

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1 Abstract

Note: The following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

This Application Note is intended to provide additional information for implementing the TLE7368 as a multiple voltage supply into new applications. The reader should be given a guidance to dimension the pre-regulator output filter, dimension the component values (filter elements) and create a proper layout.

2 Introduction

The TLE7368 is a microcontroller power supply system with a step down converter (as pre-regulator) operating at a fixed switching frequency of 370 kHz. The pre-regulator supplies several LDOs and Trackers to deliver the output voltages. The pre-regulator may also supply additional appliances if the total power consumption of the application (internal LDOs and Trackers and external loads) will not exceed 2.5 A in any condition.

The nominal value of the pre-regulator voltage is 5.5 V, but it may be lower at input voltages between 6.3 V and minimum input voltage (depending on load). The value of the LDO_1 (5.0 V) as well as Trackers 1 and 2 (also 5.0 V) might be affected.

The TLE7368 is deliverable in two versions:

- TLE7368 G or TLE7368 E: LDO_3 with 1.5 V output voltage
- TLE7368-2G or TLE7368-2E: LDO_3 with 1.2 V output voltage

The TLE7368 devices are offered in two packages:

- Power Package: TLE7368 G and TLE7368-2G
- Exposed Pad Package: TLE7368 E and TLE7368-2E

The TLE7368 has an internal power stage, but requires an output filter consisting of:

- freewheeling diode (catch diode)
- filter inductor
- the filter capacitor

The dimensioning of the output filter components is mandatory for a proper function of the converter in any load and input voltage condition:

- Freewheeling diode:
  Fast switching and capable to conduct the current, especially for starting at high input voltages. Using a Schottky diode is recommended)
- Filter inductor:
  When dimensioning the filter inductor the saturation inductance has to be considered. The inductor must not be driven into saturation in any start up or load condition, especially at high input voltage.
- Filter capacitor:
  The capacitor shall be capable of handling the current ripple resulting from the choice of the filter inductor. The use of two filter capacitors in parallel is recommended.

The following sections give guidance to dimension the filter elements.

A switch mode converter is a potential source of electromagnetic emissions (EME). EME (conducted as well as radiated) may be produced in the switch mode lines between the internal pass transistor, the freewheeling diode, the filter inductor and the filter capacitor. By means of additional filter elements, placement and dimensioning of the elements and an adapted layout of the PCB the risk of disturbing other components or the regulator itself could be reduced to zero. The goal is to achieve optimum functionality with minimum output voltage ripple and good EME performance.

An input filter is recommended for improving EME performance of the regulator. This filter reduces voltage fluctuation on the input/battery line as well as high frequency conducted disturbances produced by the pass transistor.

3 Dimensioning of Input Filter and Output Filter

This section shows how to dimension the filter elements.

3.1 Theory

Dimensioning of the filter elements is the most important issue when implementing a DC-DC converter into an application. There are two filters necessary with a step down converter:

- Input filter:
  The step down converter (or buck converter) chops the input voltage to gain voltage blocks, which will then be smoothened by the output filter to obtain the lower output voltage. Chopping the input voltage will cause current blocks, which may cause electromagnetic interference and thereby influence (disturb or degrade) other devices connected to the input voltage. Therefore an input filter has to be installed which prevents the environment from these so called "power harmonics".
- Output filter:
  The output filter smoothens the voltage blocks to a DC voltage. By design a so called "low frequent" voltage ripple (belonging to the switching frequency) will appear, which shall be as low as possible. The value of this "low frequent" voltage ripple depends on the demands of the loads, which are fed from the DC-DC converter. The permitted value of the "low frequent" voltage ripple is important for dimensioning the filter components. This "low frequent" voltage ripple is inevitable. There is also a "high frequent" voltage ripple present, which is caused by oscillations on the cathode of the freewheeling diode when the current commutes after opening the power transistor to the diode. This "high frequent" voltage ripple is most undesirable and might be (depending on the components and the layout) in a frequency range of 5 to 100 MHz. This "high frequent" voltage ripple might disturb the environment either by conducted emission or by radiated emissions. By appropriate layout and the use of additional filter measures this "high frequent" voltage ripple is avoidable or might be at least limited to an acceptable value.

Figure 1 shows the step down converter filters:

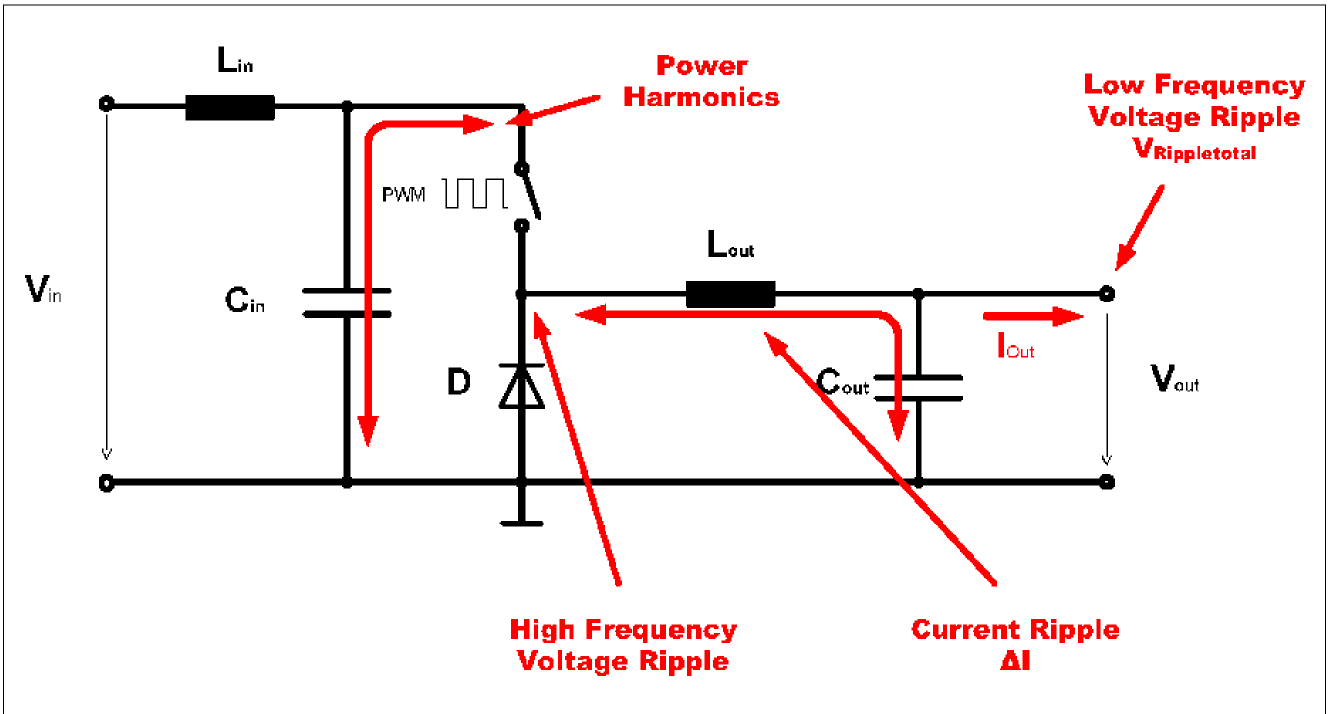

Figure 1 Step Down Filters Principle

Please be aware, that each capacitor like C_{IN} or C_{OUT} might consist of parallel parts.

The application requires a known output voltage V_{OUT}, a known load current I_{OUT} and a maximum permitted output voltage ripple $V_{Ripple,total}$. The value of the input voltage V_{IN} is also known.

This allows to calculate the output filter elements C_{OUT} and L_{OUT} under the basic assumption, that the current ripple ΔI shall not exceed 40 % of the load current I_{OUT}. Choosing ΔI smaller than 10 % of the load current I_{OUT} will lead to bigger filter elements, in value as well as in size and in price.

The capacitor has to fit the chosen ΔI (at switching frequency).

3.2 Output Filter Capacitor(s) C_{OUT}

The choice of the output capacitor determines the voltage ripple $V_{Ripple,total}$ of the output voltage. The output capacitor may be divided into several single capacitors, a single (or several) capacitor(s) must be capable to withstand the current ripple ΔI as calculated by the inductor dimensioning.

The total ripple voltage can be calculated using the following equation:

$$V_{Ripple,total} = \Delta I \cdot \left(\frac{1}{8 \cdot C_{OUT} \cdot fs} + R_{ESR}\right) \tag{3.1}$$

Where ΔI is the current ripple resulting from the choice of the output filter inductor. C is the chosen output capacitor, f_s is the switching frequency and R_{ESR} is the equivalent serial resistance of the capacitor. To improve R_{ESR} especially at load deviations an additional ceramic capacitor is recommended.

For most applications a capacitance in the range of 20 to 100 µF seems to be sufficient. ESR should be less than 150 mΩ.

3.3 Output Filter Inductor L_{OUT}

The choice of the output inductor determines the current ripple in the output filter. A lower value of the inductor reduces the physical size of the component, a higher value reduces the current ripple. For most applications an inductance in the range of 18 to 220 µH seems to be sufficient. However, the resonance frequency of the output filter shall be typically 2 kHz (tolerable range of 1 and 10 kHz), the voltage drop over the output inductor shall not exceed 0.5 V at full load.

The resonance frequency of the output filter is given by:

$$f_{RES} = \frac{1}{2\pi\sqrt{L_{OUT} C_{OUT}}} \tag{3.2}$$

During evaluation is has to be ensured, that the inductor does not get into saturation in any operation mode, especially not during ramp up. The inductor current should be considered.

A saturation value of at least 4.6 A is recommended, which according to the current limitation of the pre-regulator.

The resulting current ripple Δ*I* is given in the following equation:

$$\Delta I = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{L_{OUT} \cdot fs \cdot V_{IN}} \tag{3.3}$$

Where V_{IN} is the (nominal) Input voltage, V_{OUT} is the output voltage, f_s is the switching frequency and L_{OUT} is the output filter inductor.

The inductor can therefore be calculated by:

$$L_{OUT} = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{\Delta I \cdot fs \cdot V_{IN}} \tag{3.4}$$

3.4 Freewheeling Diode D

The diode has to be capable to conduct the current. The average current through the diode is:

$$I_{D(AVG)} = \frac{I_{OUT}\left(V_{iN} - V_{OUT}\right)}{V_{IN}} \tag{3.5}$$

Where V_{IN} is the Input voltage, V_{OUT} is the output voltage and I_{OUT} is the output current (load current). The average diode current depends on the input voltage.

- It is strongly recommended to use a freewheeling diode, which is a least capable to conduct three times the nominal load current. The choice has to be verified across the entire input voltage range, as well as in the entire output current range and in the entire temperature range.
- For fast commutating of the load current from the transistor to the diode the use of a Schottky diode is strongly recommended to avoid a negative voltage peak at the cathode and to improve efficiency.

3.5 Input Filter Capacitor(s) C_{IN}

The use of an input capacitor is mandatory. However, this capacitor may consist of several single capacitors. The capacitor(s) shall have low ESR to provide current for fast load response.

The average current through the capacitor can be calculated:

$$I_{RMS} = I_{OUT}\sqrt{D} \tag{3.6}$$

Where I_{RMS} is the current through the capacitor, I_{OUT} is the output current and D is the duty cycle.

The input capacitor will also be exposed to the switching frequency of the transistor, which will cause a current component. During evaluation it has to be ensured, that the chosen capacitor is capable to conduct this current component in the entire input voltage range, as well as in the entire output current range and in the entire temperature range.

An additional Input capacitor C_{IN} with low ESR (10 to 220 nF) close to the IN_STBY pin is recommended to suppress high frequency conducted disturbances.

3.6 Input Filter Inductor L_{IN}

It is strongly recommended to use an input inductor to form the low pass input filter. A value between 22 µF and 47 µF is sufficient. The inductor has to be capable to withstand the inrush current during start up, so a saturation current value same as the filter inductor L_{OUT} is recommended.

3.7 Testing the Output Filter Inductor L_{OUT}

The choice of the inductor should be verified to ensure that it does not enter saturation. This might easily be done during start up in any input voltage condition.

The following test was done at an input voltage of 13 V:

- Channel 1 (yellow): PWM-Pulses
- Channel 2 (light blue): output voltage
- Channel 3 (purple): current through the inductor

The current through the inductor is a sawtooth signal with straight lines, this what it should look like:

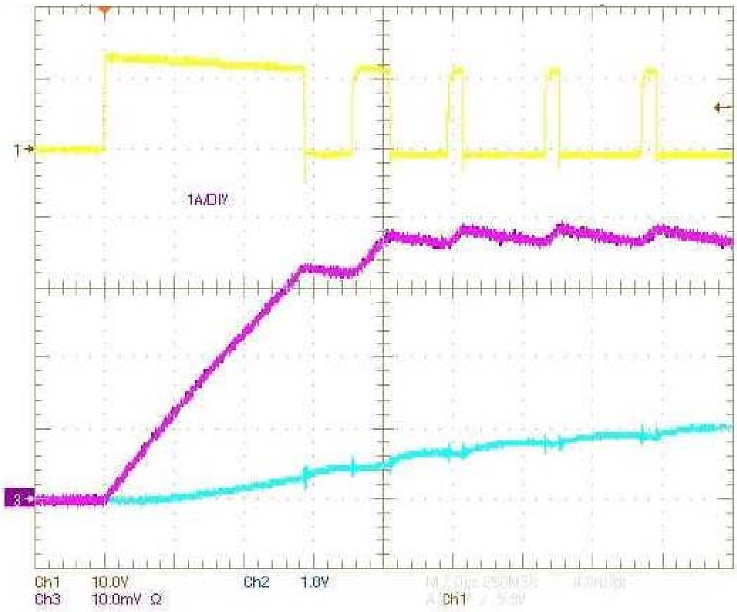

Figure 2 Soft Start

Figure 3 shows a test with an inductor of the same nominal inductance, but with a smaller saturation current. The red arrow indicates a turning point of the inductor current, which indicates saturation of the choke.

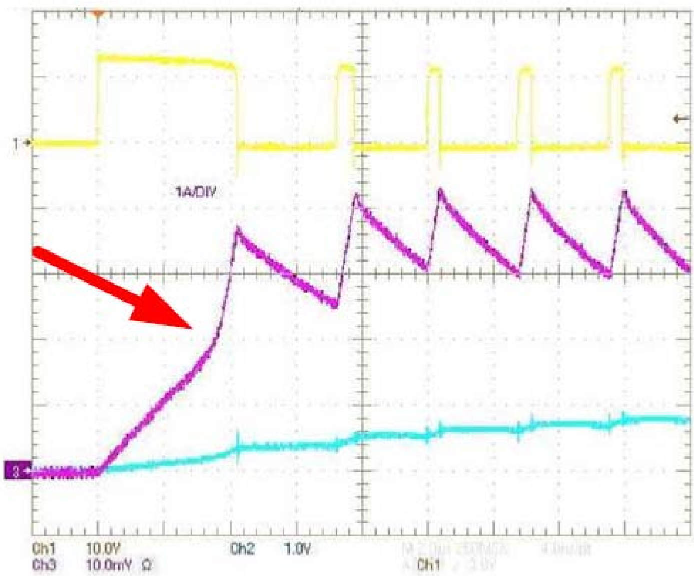

Figure 3 Soft Start with Inductor in Saturation

4 Layout recommendations

This section shall help to understand the roots of electromagnetic disturbances and assist to create a proper layout and to foresee counter measures against both conducted emission and radiated emission.

4.1 Introduction

A step down converter is a potential source of electromagnetic disturbances which may affect the environment as well as the device itself and cause sporadic malfunction up to damage, depending on the amount of noise.

We may consider the following basic effects:

- Radiated magnetic fields caused by circular currents, occurring mostly at the switching frequency and their harmonics
- Radiated electric fields, often caused by (voltage) oscillation
- Conducted disturbances (voltage spikes or oscillations) on the lines, mostly input and output lines.

The following sections discuss basic measures on how to prevent the application from such effects.

4.2 Radiated Magnetic Fields

Radiated magnetic fields are caused by circular current occurring in so called “windows”. Circular current is alternating current driven by the switching transistor. Its amplitude depends on the load current, mostly the filter current Δ*I* in the output filter and I_{RMS} in the input filter as well as on input voltage. The alternating current in these windows drives a magnetic field. The amount of magnetic emission mostly depends on the amplitude of the alternating current (which may be minimized only in the output filter by using a high inductance value) and on the size of the window. The window is the area which is defined by the circular current paths. We can distinguish two windows:

- Input current window:
  Only the alternating component of the input current I_{RMS} is considered
- Output filter current window:
  Output current ripple Δ*I*

The area of these windows has to be kept as small as possible, with the relating elements placed next to each other. It is highly recommended to use a ground plane as a single layer which covers the complete regulator area with all components shown in this figure. All connections to ground shall be as short as possible.

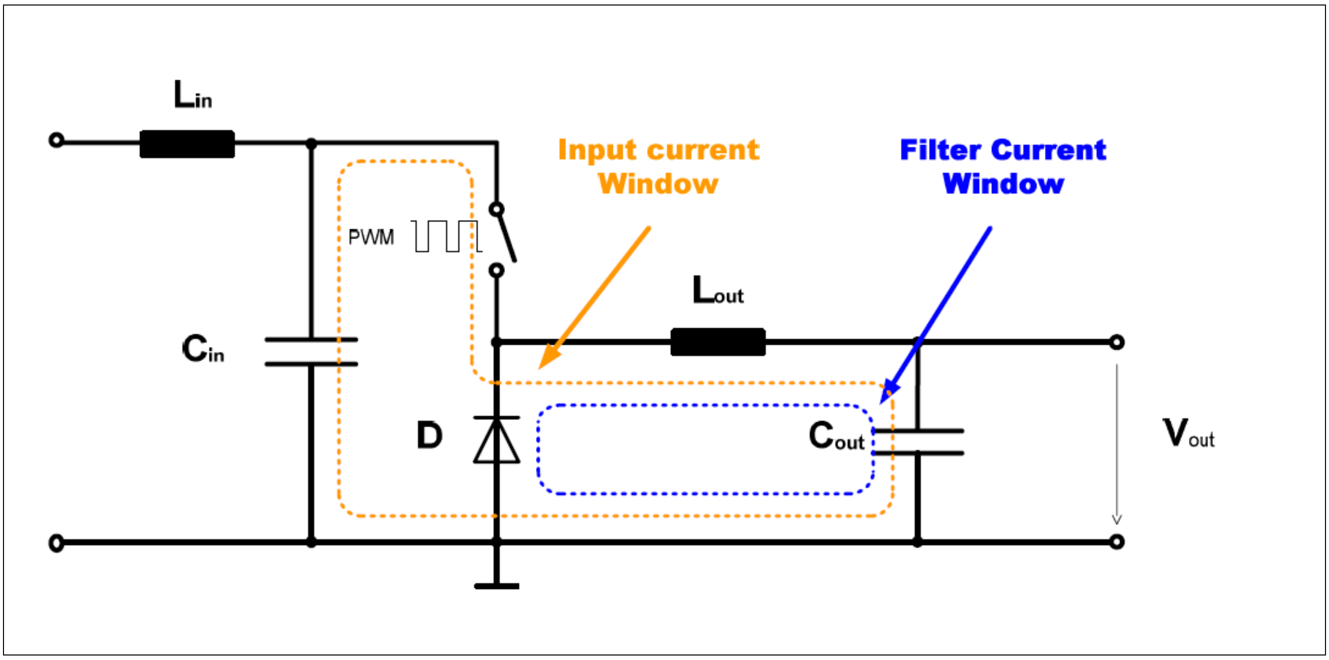

Figure 4 Circular Current Windows

4.3 Radiated Electric Fields

Radiated electric fields are caused by voltage oscillation due to stray inductance and stray capacitance at the connection between transistor, freewheeling diode and inductance. They are also of course influenced by the commutating of the load current from the transistor to the freewheeling diode. Their frequency might be between 10 and 100 MHz. Therefore it is recommended to use a fast Schottky diode and to keep the connections in this area as low inductive as possible. This can be achieved by using short and broad connections and to arrange the related parts as close as possible to each other. Following the recommendation of using a ground layer, these low inductive connections, together with the ground layer, will form small capacitances which are desirable to damp the slope of these oscillations. The oscillations use connections or wires as antennas. This effect can also be minimized by the short and broad connections.

However, by means of layout only it may not be possible to limit the oscillations to an acceptable value. Additional filtering measures could be necessary:

- Additional filter capacitors C_{Filter} (ceramic, with low ESR) in parallel to the output and input capacitor and as close as possible to the switching parts. Input and load current must be forced to pass these devices. Do not connect them via thin lines. Recommended values: 10 to 220 nF.
- R-C-snubber circuit in parallel to the freewheeling diode helps damp the oscillations, if necessary
- Additional commutation filter inductors L_{Filter}, if necessary, to smoothen commutation current and voltage peaks

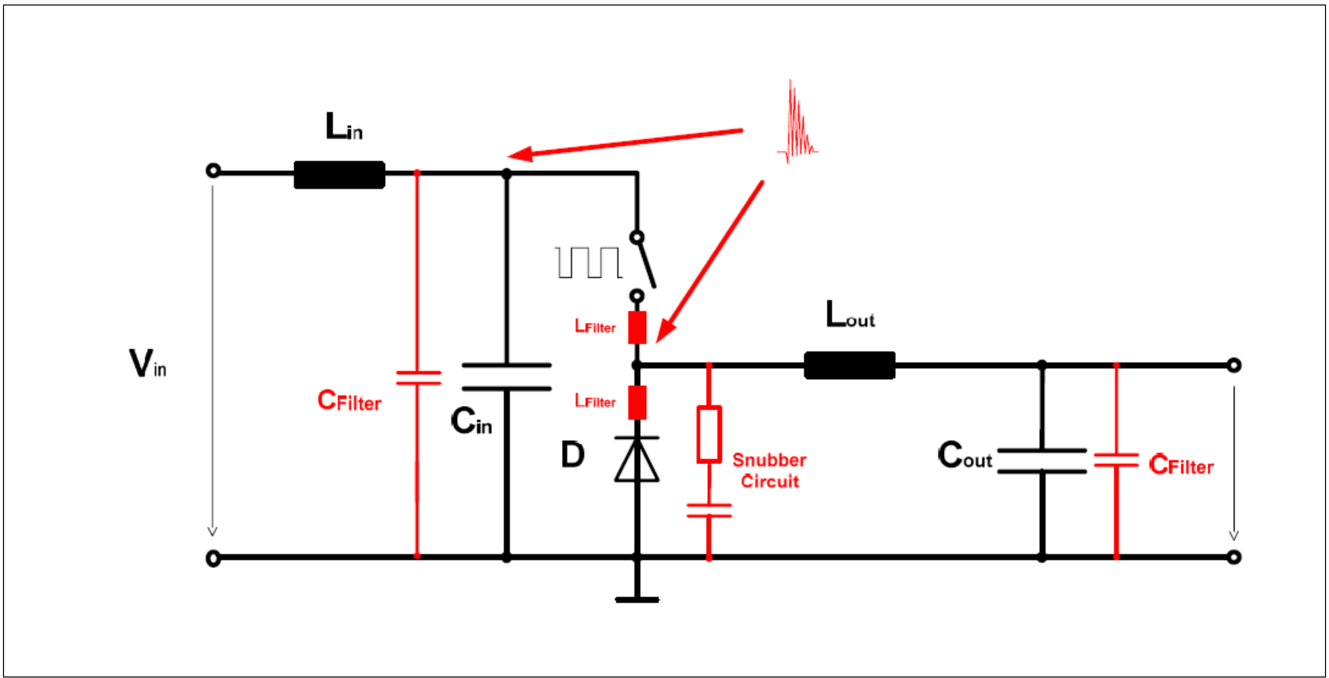

Figure 5 Additional Filtering Measures (not all shown measures (in red) may be necessary)

4.4 Conducted Disturbance

Conducted disturbance consists of voltage spikes or voltage oscillation, occurring permanently or by occasion mostly on the input or output connections. Like radiated electric fields they are caused by voltage oscillation due to stray inductance and stray capacitance at the connection between transistor, freewheeling diode and inductance.

Its frequency might be between 10 and 100 MHz. Conducted Disturbance is superimposed to input voltage and to output voltage and might thus disturb other components of the application.

Countermeasures against conducted disturbances are similar to the radiated electric fields:

- It is recommended to use short and broad connections between the single parts of the converter.
- All parts shall be mounted close to each other.
- Additional filter capacitors C_{Filter} (ceramic, with low ESR) in parallel to the output and input capacitor and as close as possible to the switching parts. Input and load current must be forced to pass these devices. Do not connect them via thin lines. Recommended values: 10 to 220 nF.
- For the input filter a π–filter for maximum suppression might be necessary, which requires additional capacitors on the input.

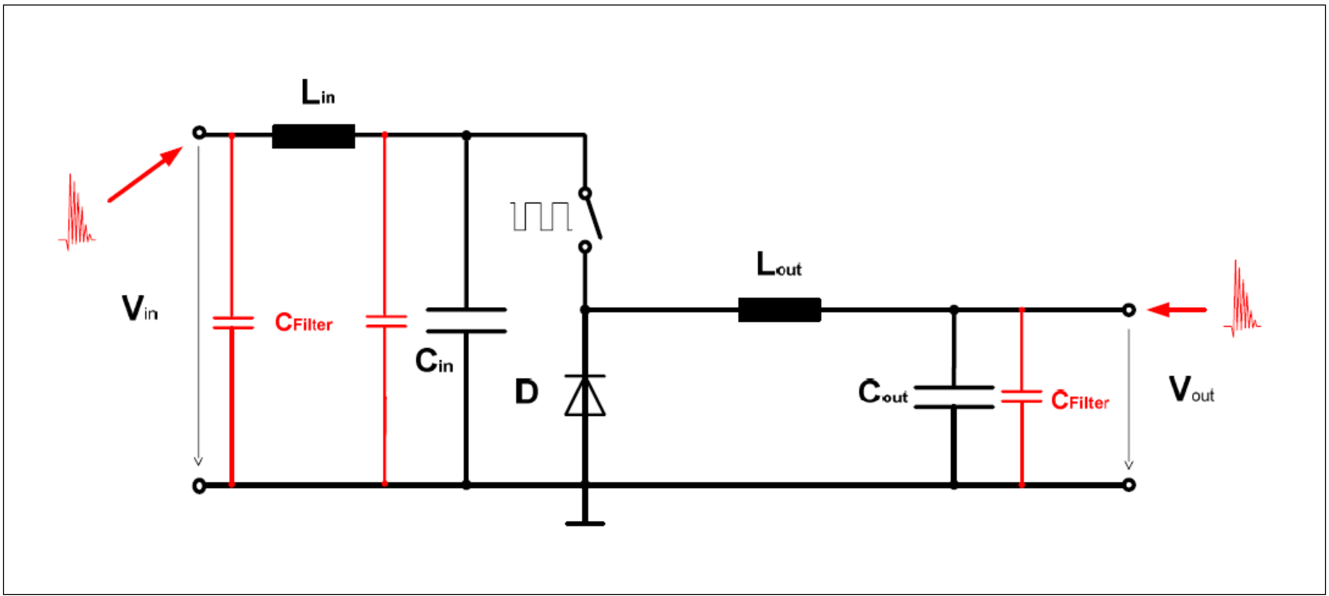

Figure 6 Additional Filtering Measures (not all shown measures (in red) may be necessary)

4.5 Summary

Please be aware that all countermeasures described above shall not be considered as single solutions to solve specific problems, respectively. Normally they have to be implemented together to achieve proper functionality of the step down converter. Please be also aware that taking all these measures may degrade efficiency.

4.6 Specific Layout Recommendations

Figure 7 gives some specific layout recommendations, please refer to **Table 1** for explanations:

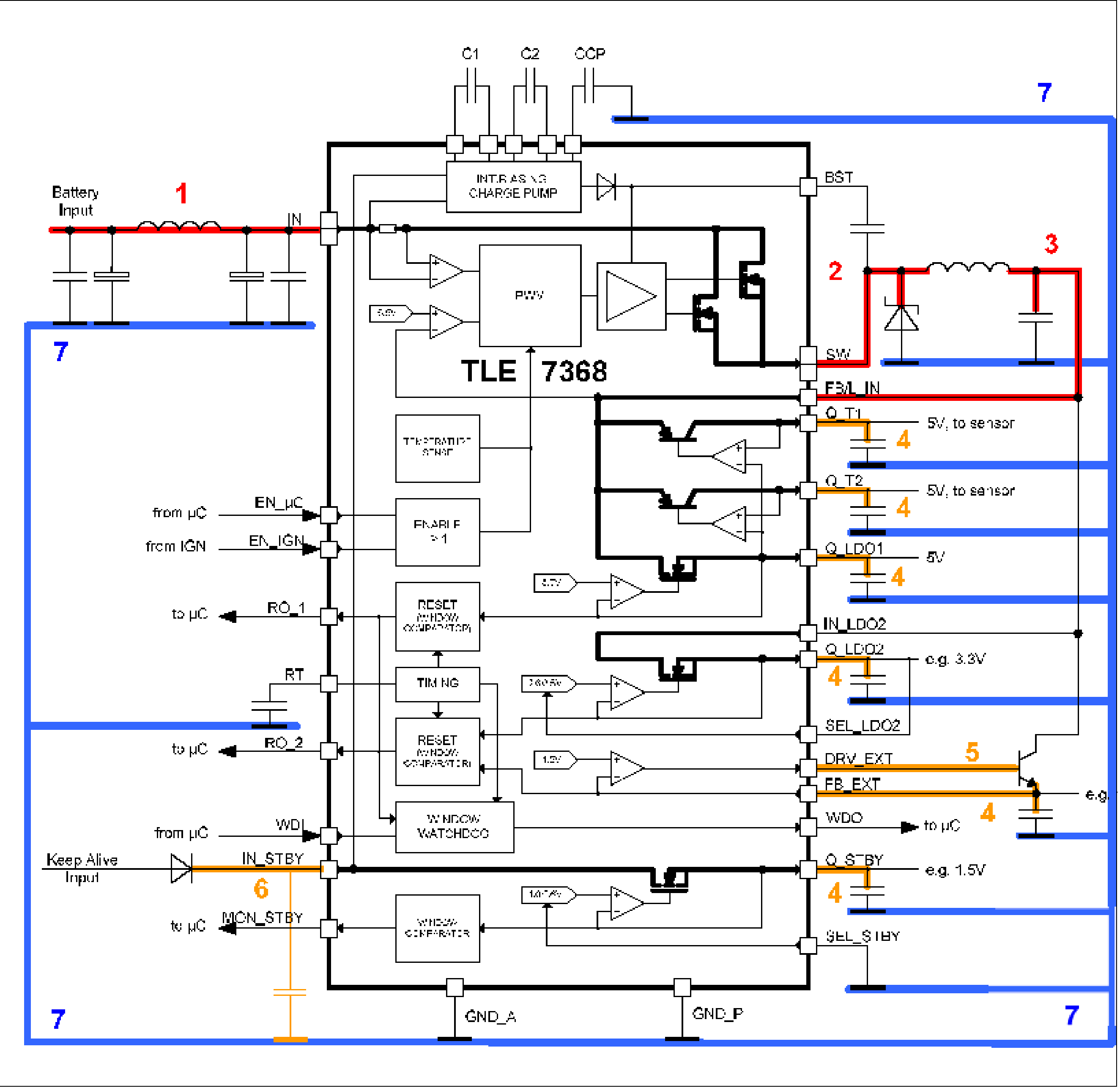

Figure 7 **Specific Layout Recommendations**

Table 1 Routing recommendations

Connection	Color	Recommendation
1	red	Input connection, between input filter (or input capacitor) and internal transistor: Shall be as short as possible, place input filter (or input capacitor) as close as possible to the IN pin, use lines as broad as possible, avoid curves or vias.
2	red	Connection between internal transistor, freewheeling diode and output filter capacitor: Shall be as short as possible, place the connected components as close as possible to each other. Use broad lines, avoid curves or vias. Make sure that the filter capacitors are mounted close to the output of the filter inductor.
3	red	Feedback line and voltage supply for LDO_1 and trackers: Connect as short as possible, avoid any vias and keep free of connection 2, do not cross or pass close by the output inductor, use a broad line.
4	orange	LDO and Tracker output capacitors: Connect as short as possible, avoid any vias and keep free of connection 2.
5	orange	LDO_3 Driver: Connect as short as possible, avoid any vias and keep free of connection 2, do not cross or pass close by the output inductor.
6	orange	Internal voltage supply: Connect a small ceramic capacitor as close as possible to the IN_STBY pin.
7	blue	Ground plane: It is highly recommended to use a ground plane as a single layer which covers the complete regulator area with all components shown in **Figure 7**. All connections to ground shall be as short as possible.

Figure 8 shows the layout of the demo board. For detailed information please refer to the demo board description.

Layout recommendations

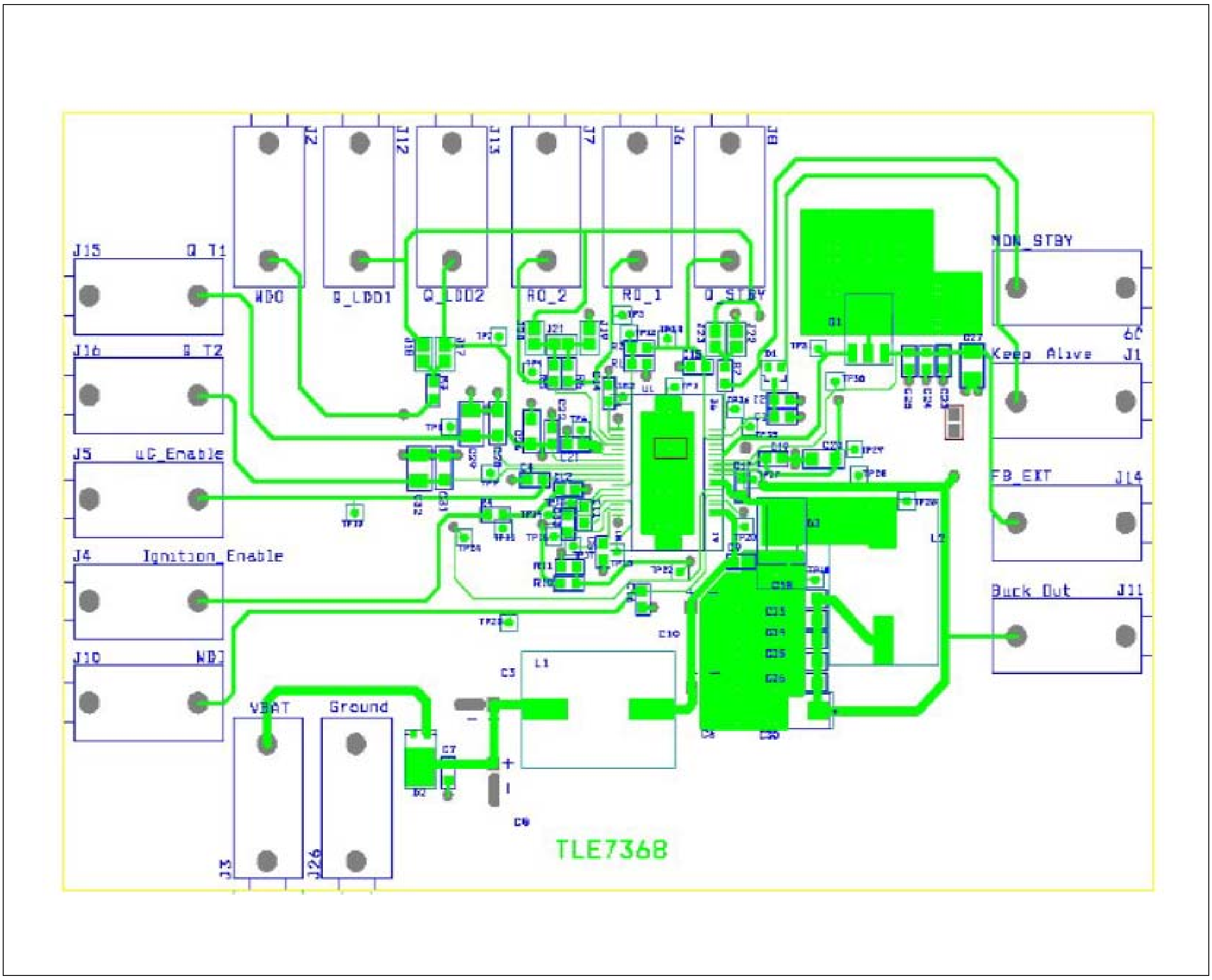

Figure 8 Layout of Demo Board

5 Additional Information

- Please contact your local Infineon representative for further assistance and additional information
- For further information you may contact **http://www.infineon.com/**

6 Revision History

Revision	Date	Changes
1.01	2015-09-22	Infineon Style Guide update (EDD41). Editorial changes.
1.0	2008-09-30	Application Note created.

www.infineon.com

Edition 2015-09-22

Published by

Infineon Technologies AG

81726 Munich, Germany

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

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Document reference
Z8F52274265

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