

# TLE8366

## Application Information

Automotive Power



Never stop thinking

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## 1 Abstract

This Application Note is intended to provide additional information for implementing the step down regulator TLE8366 as a voltage regulator into new applications. The reader should be given some additional information for developing the schematic, dimension the components (filter elements) and create a proper layout.

*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*

## 2 Introduction

The TLE8366 is a Step down Converter operating with a fixed 370 kHz switching frequency. By applying a rectangular signal to the "Sync"-Pin the switching frequency may be adjusted to an external source between 200 and 500 kHz.

The TLE8366 is deliverable in three versions:

- A fixed 5 V output voltage version, named TLE8366EV50
- A fixed 3.3 V output voltage version, named TLE8366EV33
- A variable output voltage version, named TLE8366EV  
(Output voltages adjustable between 0.60 V up to 16 V)

(The values of output voltages are depending on the value of the input voltage – the input has to be at minimum 0.70 V above the desired output voltage at full load to maintain the specified value at 100% duty cycle and output load).

The TLE8366 has an internal power stage, but requires an output filter consisting of the freewheeling (or catch-) diode, the filter inductor and the filter capacitor.

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

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

In the following sections a guidance to dimension the filter elements will be given.

Basically 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, arranging and dimensioning the elements and an adapted layout of the PCB the threat of disturbing other components or the regulator itself could be reduced to zero. The goal is to achieve an optimum in functionality with minimum output voltage ripple and good EME performance.

To improve the EME performance of the regulator an input filter is recommended. This filter will reduce voltage fluctuations on the input/battery line as well as high frequency conducted disturbances produced by the pass transistor

### 3 Dimensioning the Output and Input Filter

The following chapter shows how to dimension the filter elements:

#### 3.1 Theory

Dimensioning the filter elements is the most important issue when implementing a DC/DC converter into an application. There are basically two filters necessary on each side of the Step Down converter:

- The input filter: The Step Down (or “Buck”) converter chops the input voltage to gain voltage blocks, which will then be smoothed 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”.
- The output filter: The voltage blocks will be smoothed by this filter 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 is depending on the demands of the loads, which are fed from the DC/DC converter. The allowable 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 commutates 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 voltage range between 5 to 100 MHz. This “high frequent” voltage ripple might disturb the environment either by conducted or 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.

The Step Down converter is shown in the following figure:

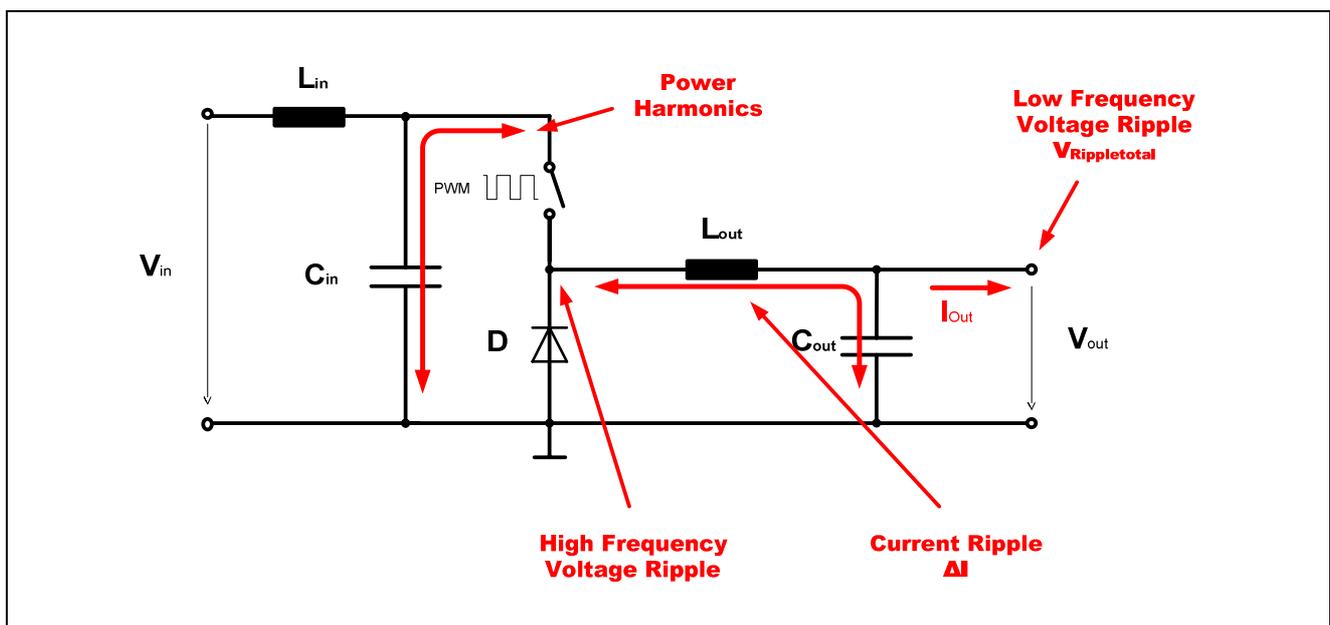


Figure 1 Step Down: Filter principle

Please be aware, that single elements like  $C_{IN}$  or  $C_{OUT}$  might be realized with parallel parts.

The application requires a known output voltage  $V_{out}$ , a known load current  $I_{OUT}$  and a maximum allowable output voltage ripple  $V_{RippleTotal}$  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  $\Delta I$  shall not exceed 40% of the load current  $I_{OUT}$ . Choosing  $\Delta I$  smaller than 10% of the load current  $I_{OUT}$  will lead to bigger filter elements. (In value, size and prize)

The capacitor has to be capable to the chosen  $\Delta I$  (occurs with the switching frequency)

### 3.2 Output Filter Capacitor(s) $C_{OUT}$

The choice of the output capacitor determines the voltage ripple  $V_{RippleTotal}$  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  $\Delta I$  as calculated by the inductor dimensioning.

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

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

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

For most applications a range of the capacitance between 33  $\mu F$  and 120  $\mu F$  seems to be sufficient, the ESR of the Capacitor is recommended to be 50 - 150 m $\Omega$ , maximum 300 m $\Omega$ .

### 3.3 Output Filter Inductor $L_{OUT}$

The choice of the output inductor determines the ripple current in the output filter. A lower value of the inductor reduces the physical size of the component, a higher value reduces the ripple current and the core lowers and allows a higher output current. For most applications a range of the inductance between 18  $\mu H$  and 56  $\mu H$  seems to be sufficient. However the resonant frequency of the output filter shall be typically 2 kHz (tolerable range between 1 and 10 kHz), the voltage drop over the output inductor shall not exceed 0.5 V under full load.

The resonant frequency of the output filter is given by:

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

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

A saturation value of at least 3.5 Amps is recommended. (3.5 Amps is the current limit of the internal power switch)

The resulting current ripple  $\Delta I$  is given in the following equation:

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

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

The inductor can therefore be calculated by:

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

### 3.4 Freewheeling Diode D

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

$$I_{D(AVG)} = \frac{I_{OUT} (V_{IN} - V_{OUT})}{V_{IN}}$$

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

- It is strongly recommended to use a freewheeling diode, which is at least capable to conduct three times the nominal load current. The choice has to be verified under consideration of the complete input voltage, output current and 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 be divided into several single capacitors. The capacitor(s) shall have a low ESR to provide current for a fast load response.

The average current through the capacitor could be calculated:

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

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 under all input voltage range, output current and temperature conditions.

An additional input capacitor  $C_{IN}$  with low ESR (10 – 220 nF) close to the VS 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 $\mu$ F and 47 $\mu$ F 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.

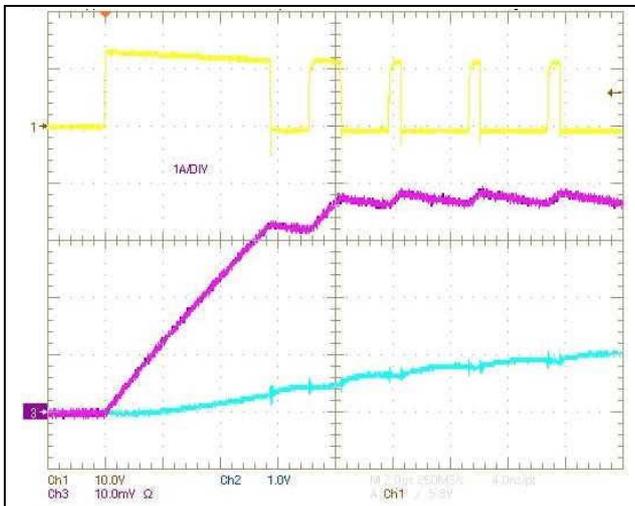
### 3.7 Output Filter Inductor $L_{OUT}$ -Test

The choice of the inductor should be verified to ensure that it does not go into saturation. This might easily be done during start up under all input voltage conditions.

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

- Channel 1 (yellow) shows the PWM-Pulses
- Channel 2 (light blue) shows the output voltage
- Channel 3 (lilac) shows the current through the inductor.

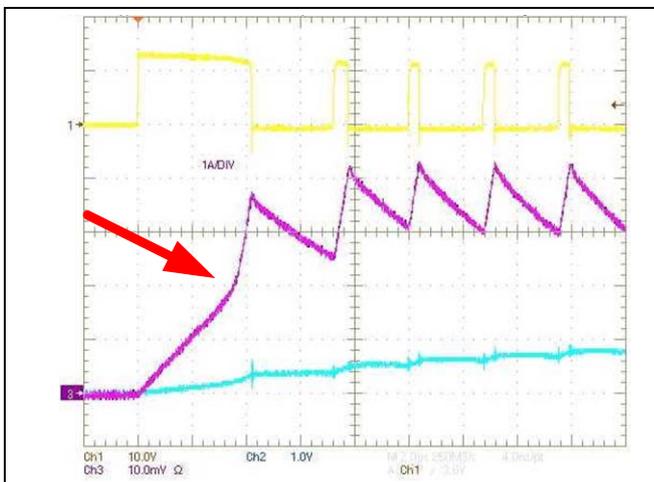
The current through the inductor is a saw tooth signal with straight lines, this how it should look like.



**Figure 2 Softstart**

In comparison to this test a different inductor of the same nominal inductance, but with a smaller saturation current limit was used

The red arrow shows, where the straight line of the inductor current has a turning –point, which indicates the saturation of the choke.



**Figure 3 Softstart, Inductor in saturation**

## 4 Layout Recommendations

The following chapter shall help to understand the roots of electromagnetic disturbances and assist to create a proper layout and to foresee counter measures against conducted and radiated emissions.

### 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 damages depending on the amount of noise.

In principal we may consider the following basic effects:

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

In the following basic measures shall be discussed, how to prevent the application from those effects.

## 4.2 Radiated Magnetic Fields:

Radiated magnetic fields are caused by circular currents occurring in so called “windows”. These circular currents are alternating currents which are driven by the switching transistor. Their amplitudes are depending on the load current, mostly the filter currents  $\Delta I$  in the output filter and the  $I_{RMS}$  in the input filter as well as from the value of the input voltage. The current alternating in these windows is driving a magnetic field. The amount of magnetic emissions is mostly depending on the amplitude of the alternating current (which may only in the output filter be minimized by using a high inductance value) and the size of the so-called “window” (this is the area, which is defined by the circular current paths. We can divide into two windows:

- The input current “window”: Only the alternate content of the input current  $I_{RMS}$  is considered
- The output filter current “window”: Output current ripple  $\Delta I$

The area of these “windows” has to be kept as small as possible, with the relating elements placed next to each others. 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

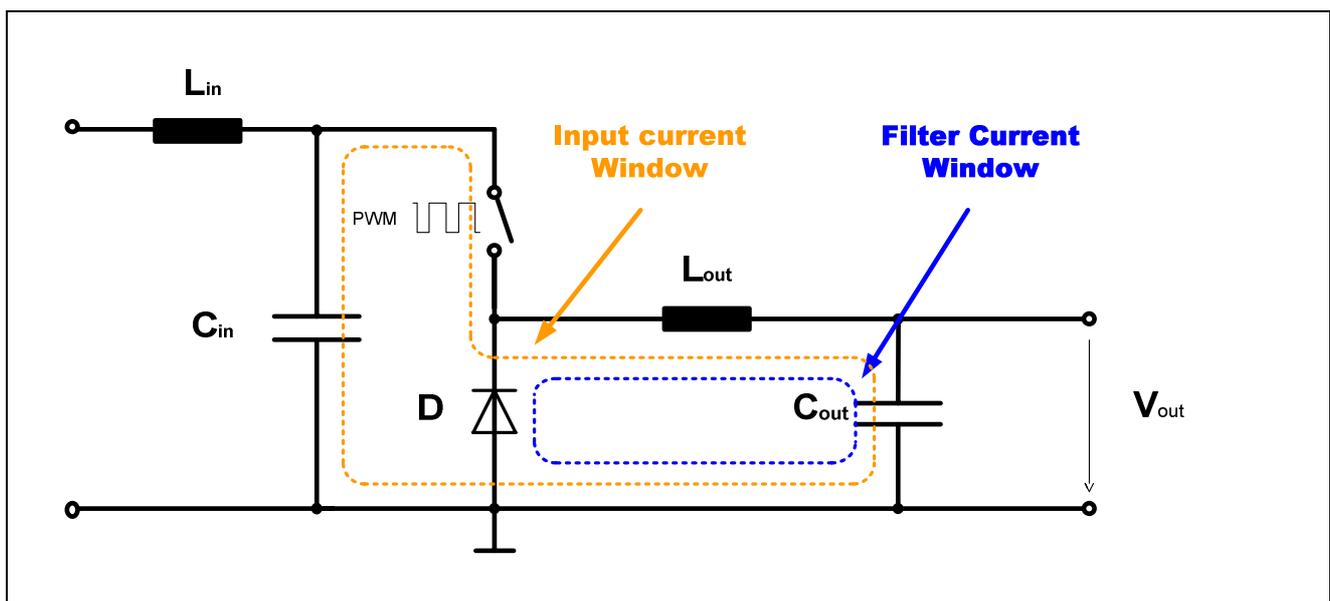


Figure 4 Circular current windows

### 4.3 Radiated Electric Fields:

Radiated electric fields are caused by voltage oscillations occurring due to stray inductances and stray capacitances 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 frequencies 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. Following the recommendation of using a ground layer these low inductive connections will form together with the ground layer 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 single means of layout it may not be possible to limit the oscillations to an acceptable value and additional filtering measures could become 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 from 10 nF to 220 nF
- R-C-snubber circuit foreseen in parallel to the freewheeling diode will help to damp the oscillations. (only if necessary)
- Additional commutation filter inductors  $L_{Filter}$  (only if necessary) to smooth commutation current and voltage peaks

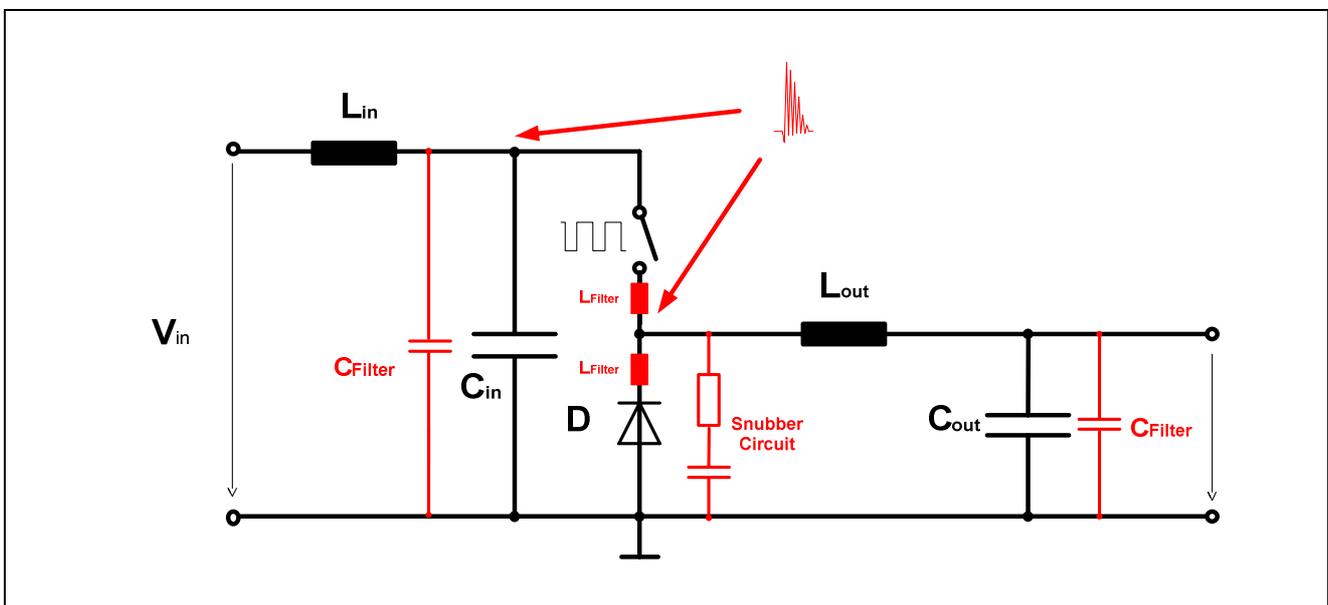


Figure 5 Additional filter measures (not all shown measures (in red) may be necessary)

#### 4.4 Conducted Disturbances:

Conducted disturbances are voltage spikes or voltage oscillations, occurring permanently or by occasion mostly on the input or output connections. Comparable to the radiated electric fields they are caused by voltage oscillations occurring due to stray inductances and stray capacitances at the connection between transistor, freewheeling diode and inductance.

Their frequencies might be between 10 and 100 MHz. They are super positioned to the input and output voltage and might thus disturb other components of the application.

The countermeasures against conducted disturbances are similar to the radiated electric fields:

- It is recommended to use short and thick connections between the single parts of the converter
- All parts shall be mounted close together
- 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 from 10 nF to 220 nF
- For the input filter a so called “T” – Filter for maximum suppression might be necessary, which requires additional capacitors on the input

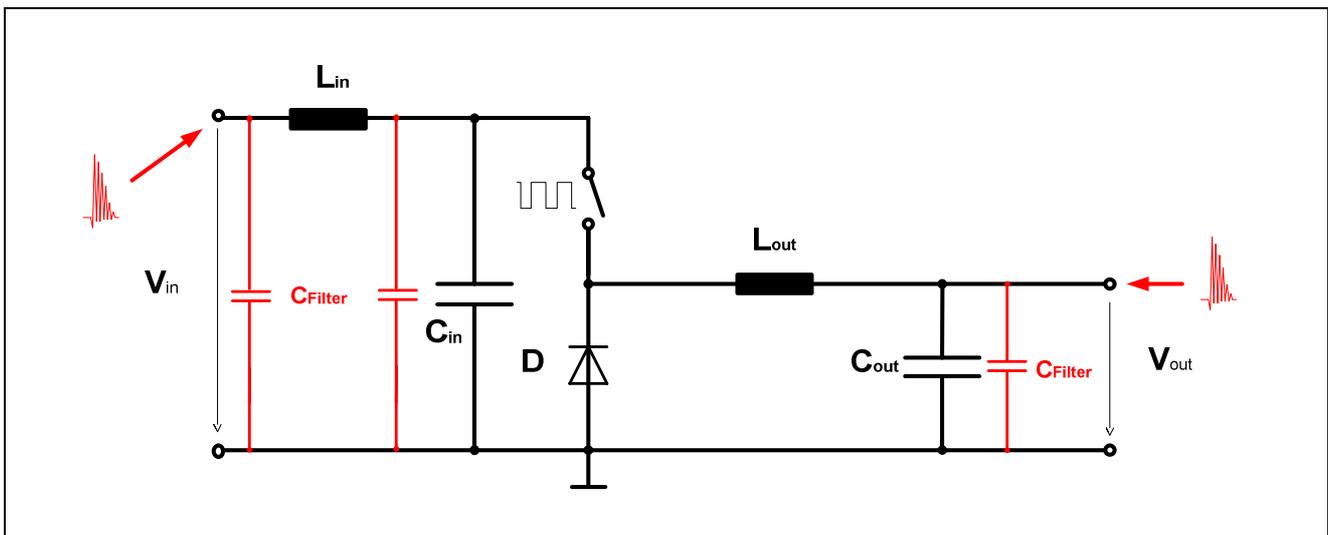


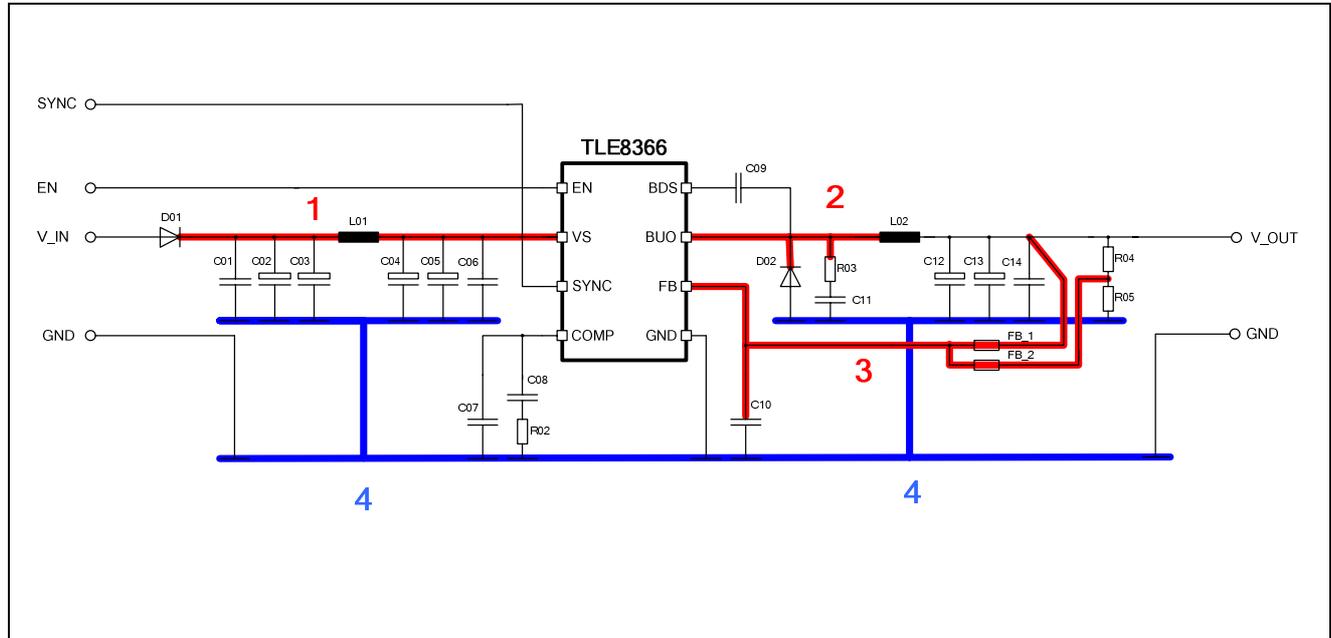
Figure 6 Additional filter measures (not all shown measures (in red) may be necessary)

#### 4.5 Summary:

In the previous chapters electromagnetic phenomena and their counter measures were described. Please be aware that all these counter measures shall not be considered as specific solutions to solve specific problems. Normally they have to be implemented together to achieve a proper functionality of the step down converter. Please be also aware that taking all these measures may degrade the efficiency.

## 4.6 Specific Layout recommendations

The following diagram shall give some specific layout recommendations, please refer to Table 1 for explanations



**Figure 7** Specific Layout recommendations (not all shown elements may be necessary for proper operation)

**Table 1** Routing recommendations

Connection	Colour	Recommendation
1	red	Input connection, between input filter (or input capacitor) and internal transistor: Shall be as short as possible, please arrange input filter (or input capacitors) as close as possible to the IN pin, use an as broad as possible lines, avoid curves or vias...
2	red	Connection between internal transistor, freewheeling diode and output filter capacitor: Shall be as short as possible, please arrange the connected components as close as possible together. Please use broad lines, avoid curves or vias. Please be sure that the filter capacitor(s) are mounted close to the output of the filter inductor.
3	red	Feedback line (for fixed and variable output voltages): 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, connect a small capacitor close to pin FB
4	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 this figure. All connections to ground shall be as short as possible

## 4.7 Layout examples

The following layout is taken the evaluation board. For detailed information please refer to the demoboard description:

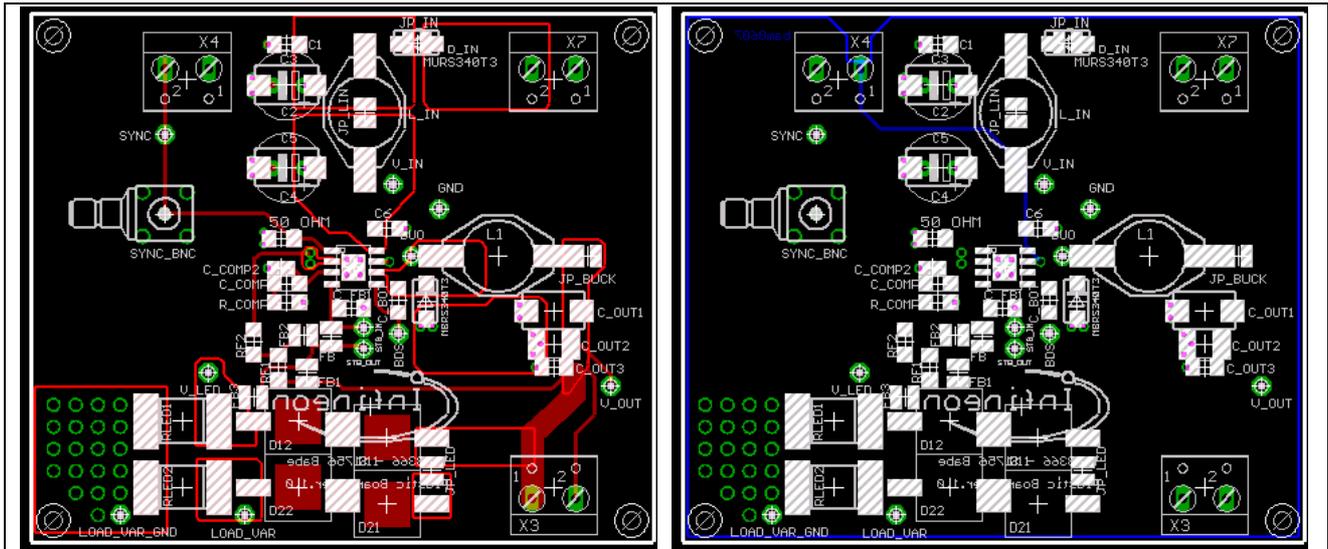


Figure 8 Evaluation Board Layout (left top layer, right bottom layer)



Figure 9 Evaluation board top view

## 5 Additional Information

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



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