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Automotive EMC considerations for switching regulator LED lighting applications using ZXLD1362

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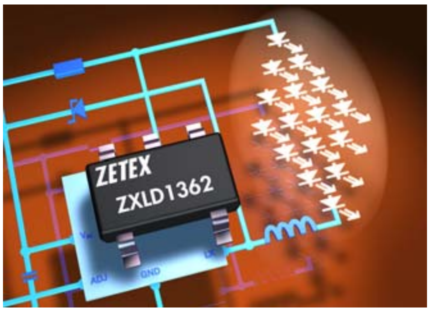
Introduction

This application note describes a driver solution developed using the Zetex ZXLD1362 LED driver IC for an automotive EMC compliant solution. ZXLD1362 switching regulator allows to maximize the efficiency gains offered by LED lighting solutions in automotive applications, while reducing the component count and the complexity of the circuit.

ZXLD1362 Description

The **ZXLD1362** hysteretic converter features can be summarized as:

- Wide input voltage range
- 7V to 60V; internal 60V NDMOS switch
- Up to 1A output current
- Capable of driving up to 16 series connected 3 Watt LEDs
- High efficiency (see datasheet - but >90% with 15 LEDs)
- Low quiescent current: (100uA typical)
- Brightness control using DC voltage or PWM (low or high frequency)
- Optional soft-start; up to 1MHz switching frequency



For more details about the hysteretic converter, please refer to the Zetex web site applications page.

Automotive EMC problems

Until now, wiring harnesses have been used to distribute power and signals throughout automotive systems. However, as can be seen in Figure 1, they are usually routed to accommodate long paths and remote LED lighting switching regulator locations are far away from the car battery. Moreover, they have parasitic inductances or capacitances which incur the adverse resonant effects associated with noise currents. As a result, there are two typical EMC problems arising with respective solutions as described in Table 1.

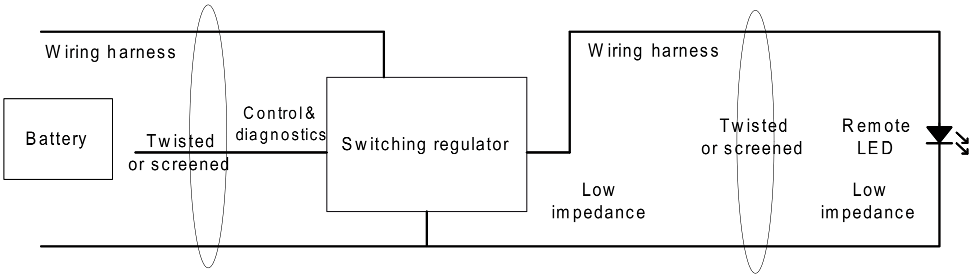


Figure 1 – A simple diagram showing remote LED from switcher

Major problem	Solution(s)
Conducted Emissions and Immunity	1. A line filter is installed on the harness close to the emission source and away from the sensitive circuits by inserting a high impedance path to the noise current flow. 2. It also minimizes the “cross talk” capacitive coupling from the device to the power supply wiring.
Radiated Emissions and Immunity	1. Cables are shielded with the termination of a low impedance path for noise currents. 2. Cables are twisted to minimize the loop area for the inductive noise coupling.

Table 1 - Automotive EMC considerations

Instead of implementing all of the above common but costly measures, it is recommended to focus on suppressing the noise source as much as possible. In the application circuit shown in Figure 2, the necessary damping circuits are therefore incorporated around the LED lighting switching regulator. Also, the use of the fast hysteretic converter can dither the switching frequency, and benefit from a lower frequency operation, which attenuates the overall emissions.

Automotive EMC standards

EMC standards in automotive lighting applications are vehicle manufacturer dependent. Table 2 summarises the automotive test standards for a generic tier 1 car manufacturer. The tests cover the supply of electrical products to a vehicle manufacturer only and do not extend to whole vehicle testing, which remains exclusively the domain of the vehicle manufacturer.

Automotive standard	Test(s) covered
CISPR-25	Conducted and Radiated Emissions
ISO 11452-2 & -4	Radiated Immunity
ISO 7637-2	Conducted Transient Immunity
ISO 10605	Electrostatic Discharge

Table 2 - Automotive test standards

The impact of operating frequency and switching topology

The choice of operating frequency and type of switching topology is important from an EMC perspective since they can yield quite different EMI performance. It is often desirable from space and cost considerations to choose a high frequency switching regulator with small inductors. However the fast edges associated with high frequency switches can cause harmonics that are difficult to damp down - a prerequisite if conducted and radiated tests are not to be failed.

Simpler hysteretic converters offer a variable frequency output, which if handled with care can produce an inherent spread spectrum response that reduces average radiated and conducted emissions. If noise filters are needed then the lowest operating frequency needs to be known to design a suitable filter.

ESD and RF immunity considerations

Switching regulators are no different from any other analogue circuit with respect to ESD. Normal system considerations should be taken into account to ensure the circuit is shielded or protected by suitable ESD diodes. The same is true for RF, although the RF levels in automotive tests are much more severe than in commercial and industrial environments. Low impedances are more immune than high impedances. This is particularly important on dimming control and status pins.

Interior lighting application using ZXLD1362

Figures 2 and 3 show the schematic and the board view of a 350mA LED driver circuit using ZXLD1362, for car interior lighting respectively. The circuit is intended to be implemented with the LED remote from the switching circuit which is also connected to the battery via long wires.

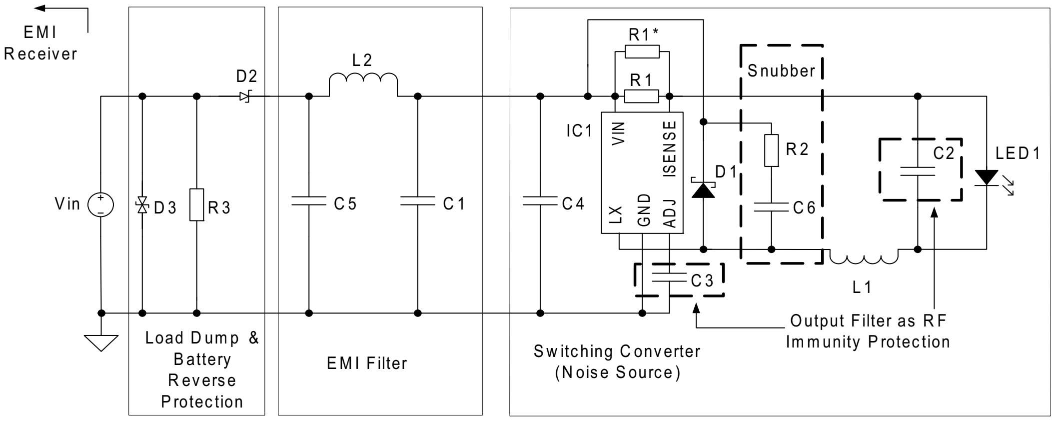


Figure 2 - Circuit diagram of a ZXLD1362 LED driver for car interior lighting

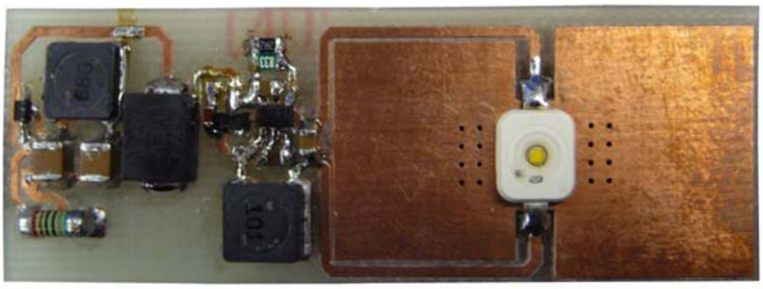


Figure 3 - Circuit board view

EMC measures for ZXLD1362 hysteretic converter

In order to properly dissipate the heat generated by a power LED, it is often required to expose an adequate copper area on both sides of the PCB together with a number of interconnecting thermal vias for soldering and heat transfer. As a result, the routing of a long path to the LED is unavoidable. So a capacitor C_2 is added not only to reduce the LED ripple current but also to filter its noise current. In some worst cases, an extra common mode choke may need to be inserted.

For this lighting solution a 60V ZXLD1362 based buck converter employing hysteretic current control was used. With reference to Figure 2 the full EMC solution consists of the following measures: For load dump protection a bidirectional transient suppressor diode D_3 is added. Its fast instantaneous clamping response to high transient over-voltages with high peak pulse power makes it ideally suited to this particular function. The EMI filter consists of an inductor L_2 and two capacitors C_1 and C_5 that form a simple Π filter which attenuates the conducted EMI. A capacitor C_3 of 10nF is connected from ADJ pin to ground to filter noise pickup which may create flickering during the immunity test. An optional basic RC snubber (R_2-C_6) could be connected across the diode D_1 to control both the spike's transition rate and shape. The capacitor controls the rise time and the resistor the peak voltage. In fact this was not required to meet the EMC test conditions but EMC measures are better to be designed in and removed rather than retrofitted. Cores of both the switching inductor L_1 and the filter inductor L_2 are shielded, ferrite-based and closed magnetic field type, in order to provide suppression of radiated emissions as well as immunity to external fields.

EMI filter design analysis

ZXLD1362 is a hysteretic LED driver that guarantees a constant current on the LED with a very simple circuit. The hysteretic converter is a variable frequency topology. EMI filters need to be designed to take into account the lowest operating frequency. In order to successfully attenuate the switcher noise a 4th-order low-pass Π filter, is formed by C_5, L_2 and C_1. The filter offers more than 60dB attenuation at 300 kHz according to the transfer function analysis using Millman's Theorem. The resulting filter attenuation is also shown in Figure 4.

$$\frac{V_O(s)}{V_I(s)} = \frac{1}{L_S L_2 C_1 C_5}\left[\frac{1}{s^4 + \frac{1}{C_5 R_L}s^3 + \left(\frac{1}{L_S C_1} + \frac{1}{L_2 C_1} + \frac{1}{L_2 C_5}\right)s^2 + \frac{1}{C_1 C_5 R_L}\left(\frac{1}{L_S} + \frac{1}{L_2}\right)s + \frac{1}{L_S L_2 C_1 C_5}}\right]$$

$$= 1.331\times 10^{23}\left(\frac{1}{s^4 + 4.256\times 10^{13}s^2 + 1.331\times 10^{23}}\right) \qquad \text{For } R_L >> 1$$

where:

$V_I(s)$ stands for the noise source

$V_O(s)$ stands for the EMI receiver

R_L accounts for the loading impedance of the EMI receiver

L_S accounts for the parasitic trace inductance

In this example, we have

L_2=68µH; C_1=C_5=4.7µF; L_S=5nH

In the circuit, the switching frequency at V_{IN}=12V is calculated to be about 300 kHz based on the below derivation with reference to the ZXLD1362 internal block diagram as shown in the datasheet.

$$f_{SW} = \frac{1}{\frac{L\Delta I}{V_{IN} - V_{LED} - I_{AVG}(R_S + rL + R_{LX})} + \frac{L\Delta I}{V_{LED} + V_D + I_{AVG}(R_S + rL)} + 2T_{PD}}$$

where:

L is the coil inductance (H)

rL is the coil resistance (Ω)

I_{AVG} is the required LED current (A)

ΔI is the coil peak-peak ripple current (A) {Internally set to 0.3 x I_{AVG}}

V_{IN} is the supply voltage (V)

V_{LED} is the total LED forward voltage (V)

R_{LX} is the switch resistance (Ω)

V_D is the diode forward voltage at the required load current (V)

T_{PD} is the internal comparator propagation delay

The following necessary parameters are used for the substitution into the above equation.

L=L_1=100µH

rL=0.48Ω

I_{AVG}=348.5mA

ΔI=104.5mA

V_{IN}=12V

V_{LED}=3.8V

R_{LX}=1.5Ω

V_D=375mV at I_F=348.5mA

R_S=R_1//R_1*=0.33Ω//2.2Ω=0.287Ω

T_{PD}=200ns

As such, the filter has been optimized to provide enough attenuation at the fundamental frequency as well as its harmonics in order to meet the conducted EMI requirement only with the simplest structure.

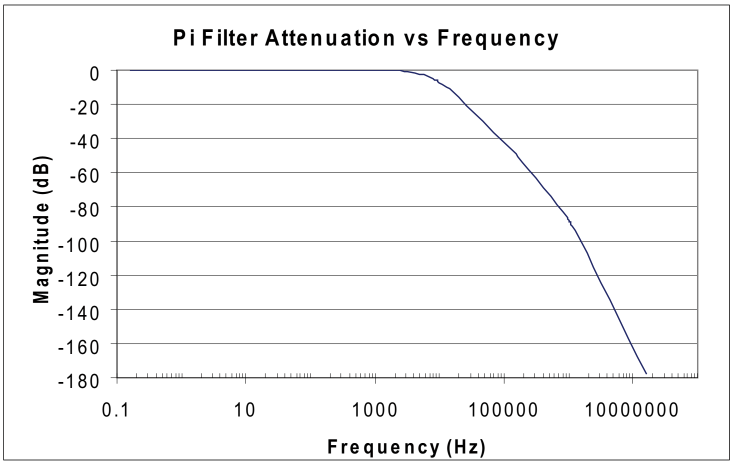


Figure 4 - Π filter attenuation vs frequency

Results/graphs for EMI and susceptibility

The EMC test results are shown in Figures 5, 6 and 7 in accordance with the following automotive standards with limit lines identified by the customer.

CISPR-25: Conducted and radiated emissions (Europe and Worldwide standards)

ISO11452: Radiated immunity (North America and Worldwide standards)

95/54/EC: Radiated emissions (European standards)

It should be noted that the radiated immunity test is correlated by the strip-line measurement inside a GTEM cell while the radiated emission test is correlated by the absorber chamber verification using an active loop antenna at 1m range.

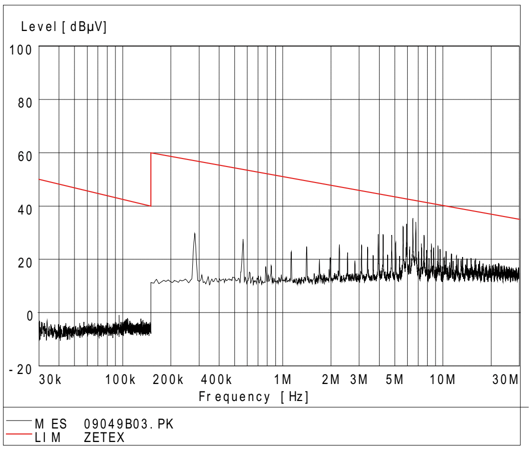


Figure 5 - Conducted EMI scan

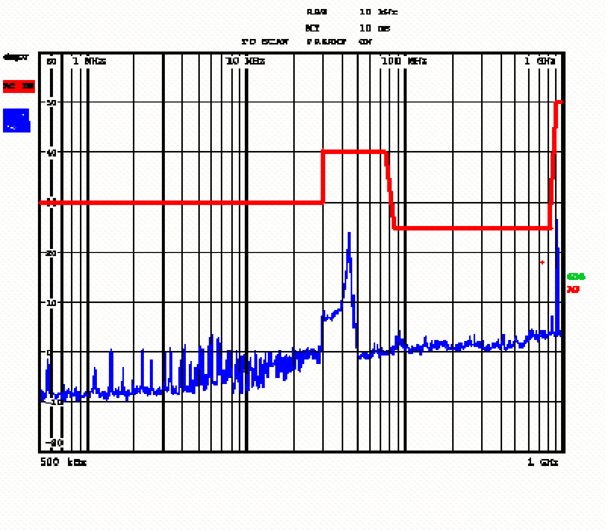


Figure 6 – Operating emission using GTEM

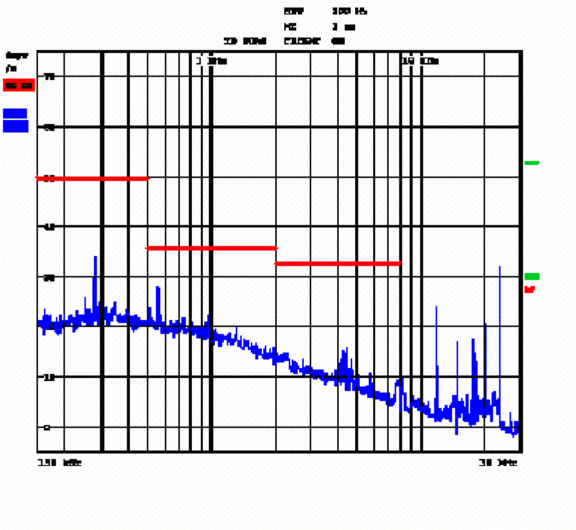
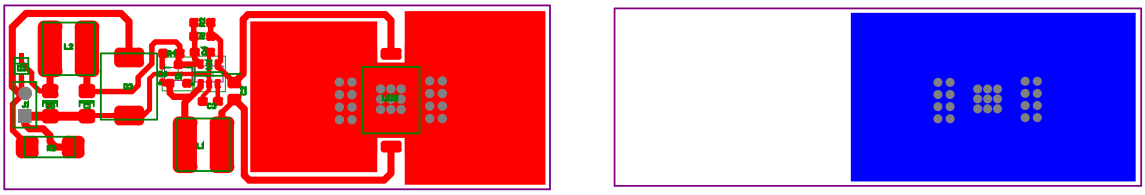


Figure 7- Operating emission with loop antenna in 1m range

PCB layout considerations and bill of materials

In designing for EMC, PCB layout plays a critical role in producing an effective solution. For this design the following measures were taken as implemented in Figure 8.



Top copper sillscreen

Bottom copper silkscreen

Figure 8 - Circuit layout

- The capacitor C_3 connected from ADJ pin to ground is as short as possible.
- The high di/dt loop (L_X-D_1-V_{IN}-C_4) with a fast switching current is made as small as possible. This minimises the differential mode noise related the loop inductance multiplied by the fast transient switching (L·di/dt).
- A simple Π filter (C_5-L_2-C_1) is placed as close as possible to the input terminals performing the optimal conducted EMI attenuation.
- The perpendicular configuration of the EMI filter components lowers the capacitive coupling between the inductor and capacitors.
- A V-connection of the filter capacitors C_1 and C_5 helps prevent self resonance and so avoids degrading the EMI performance.
- Careful component placement avoids the mutual coupling of noise generating nodes to noise sensitive nodes.

Ref.	Value	Package	Part number	Manufacturer	Description
C1, C5	4.7µF/50V	1210	GRM32ER71H475KA88	Murata	SMD capacitor
C2	1µF/25V	0805	GRM21BR71E105K	Murata	SMD capacitor
C3	10nF/50V	0805	GRM21BR71H103K	Murata	SMD capacitor
C4	0.1µF/50V	0603	GCM188R71H104KA57	Murata	SMD capacitor
C6	Open	0603	B37931-K5XXX-K70	Murata	SMD capacitor
D1	40V/1.16A	SOT23	ZLLS1000	Diodes Inc	Low leakage schottky diode
D2	40V/0.52A	SOD323	ZLLS400	Diodes Inc	Low leakage schottky diode
D3	N/A	SMC	SMCJ36CA	Diodes Inc	SMD bidirectional transient voltage suppressor
IC1	N/A	TSOT23-5	ZXLD1362	Diodes Inc	1A LED driver with internal switch
L1	100µH	Type LH	WE-TPC 744053101	Würth Elektronik	SMD-shielded tiny power inductor
L2	68µH	Type L	WE-TPC 744052680	Würth Elektronik	SMD-shielded tiny power inductor
LED 1	N/A	SMD CLC	LW W5SM	Osram	Golden Dragon
R1	0.33Ω	0805	RL1220S-R33	Cyntec	SMD resistor
R1*	2.2Ω	0805	RL1220-2R2	Cyntec	SMD resistor
R2	Open	0805	RL1220S-XXX	Cyntec	SMD resistor
R3	680Ω	MELF	SMM0207 50 680R 1%	Vishay	Metal film, cylindrical resistor

Table 3 - Bill of materials

Conclusion

Successful implementation of a switching regulator to drive LEDs can be achieved in the tough automotive environment using ZXLD1362. Defensive measures must be designed to cope with conductive and radiated emissions as well as creating a robust RF immune system.

Since the choice of topology, circuit design and PCB layout are essential to ensure the lighting solution operates correctly in an automotive application, this application note described how to manage these tasks using the ZETEX LED driver ZXLD1362.

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