AN57
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
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.

<table>
<thead>
<tr>
<th>Automotive standard</th>
<th>Test(s) covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>CISPR-25</td>
<td>Conducted and Radiated Emissions</td>
</tr>
<tr>
<td>ISO 11452-2 &amp; -4</td>
<td>Radiated Immunity</td>
</tr>
<tr>
<td>ISO 7637-2</td>
<td>Conducted Transient Immunity</td>
</tr>
<tr>
<td>ISO 10605</td>
<td>Electrostatic Discharge</td>
</tr>
</tbody>
</table>

Table 2 - Automotive test standards

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.

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**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 C₂ 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 D₃ 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 L₂ and two capacitors C₁ and C₅ that form a simple II filter which attenuates the conducted EMI. A capacitor C₃ 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 (R₂-C₆) could be connected across the diode D₁ 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 L₁ and the filter inductor L₂ 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 II filter, is formed by C₅, L₂ and C₁. 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.

\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{L_s L_2 C_1 C_5} \left[ \frac{1}{s^4 + \frac{1}{C_5 R_L} s^3 + \left( \frac{1}{L_s C_1} + \frac{1}{L_2 C_1} + \frac{1}{L_2 C_3} \right) s^2 + \frac{1}{C_1 C_5 R_L} \left( \frac{1}{L_s} + \frac{1}{L_2} \right) s + \frac{1}{L_s L_2 C_1 C_5} \right] \\
= 1.331 \times 10^{23} \left( \frac{1}{s^4 + 4.256 \times 10^{13} s^2 + 1.331 \times 10^{23}} \right) \quad \text{For} \ R_L \gg 1
\]

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

\[ L_2 = 68 \mu\text{H}; \quad C_1 = C_5 = 4.7 \mu\text{F}; \quad L_S = 5 \text{nH} \]

In the circuit, the switching frequency at \( V_{\text{IN}} = 12 \text{V} \) 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.

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

where:

- \( L \) is the coil inductance (H)
- \( rL \) is the coil resistance (Ω)
- \( I_{\text{AVG}} \) is the required LED current (A)
- \( \Delta I \) is the coil peak-peak ripple current (A) (Internally set to 0.3 \times I_{\text{AVG}})
- \( V_{\text{IN}} \) is the supply voltage (V)
- \( V_{\text{LED}} \) is the total LED forward voltage (V)
- \( R_{\text{LX}} \) is the switch resistance (Ω)
- \( V_D \) is the diode forward voltage at the required load current (V)
- \( T_{\text{PD}} \) is the internal comparator propagation delay

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

- \( L = L_1 = 100 \mu\text{H} \)
- \( rL = 0.48 \Omega \)
- \( I_{\text{AVG}} = 348.5 \text{mA} \)
- \( \Delta I = 104.5 \text{mA} \)
- \( V_{\text{IN}} = 12 \text{V} \)
- \( V_{\text{LED}} = 3.8 \text{V} \)
- \( R_{\text{LX}} = 1.5 \Omega \)
- \( V_D = 375 \text{mV} \) at \( I_F = 348.5 \text{mA} \)
- \( R_S = R_1//R_1^* = 0.33\Omega//2.2\Omega = 0.287\Omega \)
- \( T_{\text{PD}} = 200\text{ns} \)

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.
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.
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.

Figure 6 – Operating emission using GTEM  
Figure 7- Operating emission with loop antenna in 1m range

Figure 8 - Circuit layout
• The capacitor $C_3$ connected from ADJ pin to ground is as short as possible.
• The high $di/dt$ loop ($L_X\cdot D_1\cdot V_{IN}\cdot C_4$) 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 ($L\cdot di/dt$).
• A simple II filter ($C_5\cdot L_2\cdot C_1$) 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.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Value</th>
<th>Package</th>
<th>Part number</th>
<th>Manufacturer</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>C1,</td>
<td>4.7µF/50V</td>
<td>1210</td>
<td>GRM32ER71H475KA88</td>
<td>Murata</td>
<td>SMD capacitor</td>
</tr>
<tr>
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<td>1µF/25V</td>
<td>0805</td>
<td>GRM21BR71E105K</td>
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<td>10nF/50V</td>
<td>0805</td>
<td>GRM21BR71H103K</td>
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<td>SMD capacitor</td>
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<tr>
<td>C4</td>
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<td>0603</td>
<td>GCM188R71H104KA57</td>
<td>Murata</td>
<td>SMD capacitor</td>
</tr>
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<td>0603</td>
<td>B37931-K5XXX-K70</td>
<td>Murata</td>
<td>SMD capacitor</td>
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<tr>
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<td>SOT23</td>
<td>ZLLS1000</td>
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<td>Low leakage schottky diode</td>
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<tr>
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<td>SOD323</td>
<td>ZLLS400</td>
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<td>Low leakage schottky diode</td>
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<tr>
<td>D3</td>
<td>N/A</td>
<td>SMC</td>
<td>SMCD36CA</td>
<td>Diodes Inc</td>
<td>SMD bidirectional transient voltage suppressor</td>
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<tr>
<td>IC1</td>
<td>N/A</td>
<td>TSOT23-5</td>
<td>ZXLD1362</td>
<td>Diodes Inc</td>
<td>1A LED driver with internal switch</td>
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<td>L1</td>
<td>100µH</td>
<td>Type LH</td>
<td>WE-TPC 744053101</td>
<td>Würth</td>
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</tr>
<tr>
<td>L2</td>
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<td>Type L</td>
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<td>Würth</td>
<td>SMD-shielded tiny power inductor</td>
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<td>LW W5SM</td>
<td>Osram</td>
<td>Golden Dragon</td>
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<td>SMD resistor</td>
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<tr>
<td>R1*</td>
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<td>0805</td>
<td>RL1220-2R2</td>
<td>Cyntec</td>
<td>SMD resistor</td>
</tr>
<tr>
<td>R2</td>
<td>Open</td>
<td>0805</td>
<td>RL1220S-XXX</td>
<td>Cyntec</td>
<td>SMD resistor</td>
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<tr>
<td>R3</td>
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<td>MELF</td>
<td>SMM0207 50 680R 1%</td>
<td>Vishay</td>
<td>Metal film, cylindrical resistor</td>
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</table>

**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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Issue 1 - September 2008 © Diodes Incorporated 2008