DN89
MR16 EMC compliant reference design

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Introduction

As a supplement to DN86, this design note aims at depicting the essential EMC tests for a stand-alone MR16 lamp with up to three power LEDs in series at 350mA. The LED driver is simply implemented by a switching buck regulator employing the ZXLD1350 hysteretic current controller with the ZXSBMR16PT8 dedicated and new full bridge/freewheeling combo extremely low leakage schottky diodes. Throughout the compliant verification, the driver was operated from a 12Vac source by means of a typical linear step down transformer directly connected to AC mains. For the demonstration purpose, the application circuit diagram along with the part list is presented as a ready-to-use reference design tool.

Circuit description

In MR16 lamp applications, the hysteretic converter is more preferable than the fixed frequency PWM converter because of the reduced component count and its lower switching frequency that minimizes the radiated emissions. Furthermore, an EMI filter along with frequency dithering is adequate for conducted emission attenuation as well as better immunity.

The basic circuit with the EMC modifications is shown in Figure 1.

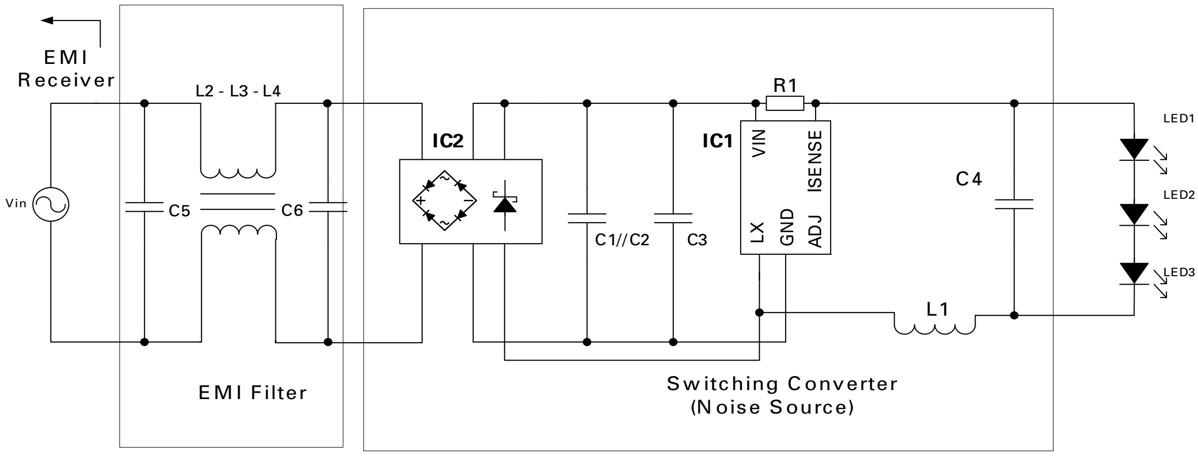


Figure 1 - System diagram of ZXLD1350 MR16 lamp solution with an EMI filter

The LED driver is simply implemented by a switching buck regulator employing the ZXLD1350 integrated controller with the ZXSBMR16PT8 dedicated and full bridge/freewheeling combination extremely low leakage schottky diodes. The controller has an internal switch that greatly reduces both the PCB size and the component count. Two input energy storage SMD tantalum capacitors; C_1+C_2, of total value 300uF have been optimized as the minimum capacitance in terms of efficiency and LED current accuracy.

The following components were needed for EMC considerations. Three 0805 type SMD common-mode chokes in series, L_2, L_3 and L_4, were verified to be the minimum requirement to pass the conducted EMI test. A screened inductor L_1 is selected to minimize the radiated EMI from the switching operation.

The variable switching frequency of the system can be derived as below with reference to the ZXLD1350 internal block diagram as shown in the datasheet.

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

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

In this example, we have

$L=L_1=100\mu H \pm 10\%$
$rL=0.82\Omega$
$I_{AVG}=303mA$
$\Delta I=90.91mA$
$V_{IN}=14.5V \pm 2.5V$
V_{LED}=8.7V~12.3V (typical 10.8V)
$R_{LX}=1.5\Omega$ (max. 2Ω)
V_D=420mV (max. 485mV) at I_F=303mA
$R_S=R_1=0.33\Omega$
$T_{PD}=200ns$

As can be calculated, the inherent variation of the switching frequency in relation to the input variation of 14.5V±2.5V is an advantage. It was found to be from around 24 kHz at minimum voltage to 420 kHz in the peak voltage in a worse case analysis. In this way, the ZXLD1350 offers a ±90% deviation of its nominal switching frequency of 230 kHz thereby facilitating the frequency dithering. The effect is shown in Figure 2.

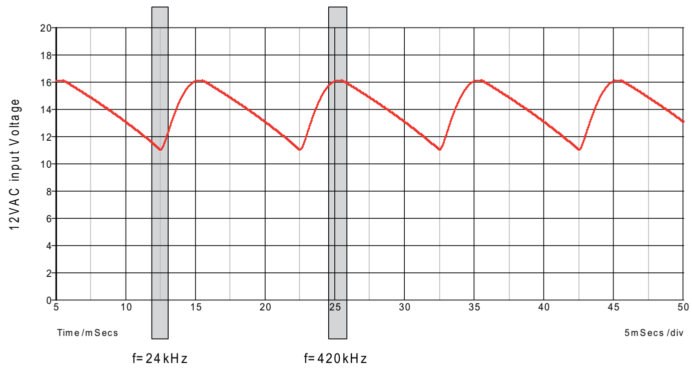


Figure 2 - Switching frequency variation with 12Vac input voltage

In addition, an EMI filter is composed of two X-capacitors, C_5 and C_6, and three common-mode chokes in series, L_2, L_3 and L_4. The 3dB cutoff frequency f_C is estimated as below.

Half inductance of an individual common-mode choke = $L_{1/2} = \frac{Z}{2\pi f} = \frac{67}{2\pi \times 100 \times 10^6} = 0.1066\mu H$

Total inductance of all common-mode chokes = $L_{SUM} = L_2 + L_3 + L_4 = 3 \times 2 \times L_{1/2} = 0.6396\mu H$

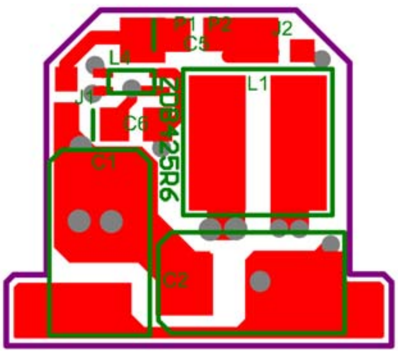
$\therefore$ 3dB cutoff frequency f_C = $\frac{1}{2\pi\sqrt{L_{SUM}C_5}} = \frac{1}{2\pi\sqrt{0.6396 \times 10^{-6} \times 1 \times 10^{-6}}} = 200\text{kHz}$

Hence, the filter can provide a supplementary attenuation of -40dB/decade from 200 kHz. This is just below the nominal switching frequency. In other words, it is effective to suppress the higher harmonics.

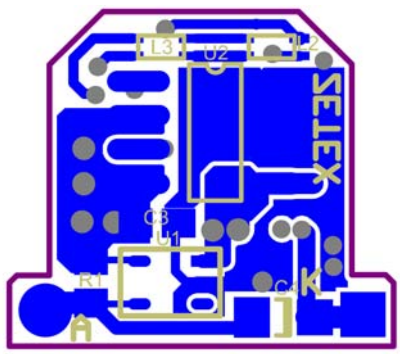
PCB layout considerations

There are many critical EMC considerations in the PCB layout as below:

- A star ground connection is employed to avoid the common impedance effect
- A ground ring is used to protect the ADJ pin against any kind of electromagnetic coupling
- The sense tracks connecting R1 to ZXLD1350 are as short as possible
- The decoupling capacitor C3 is placed as close as possible to the Vin pin
- The freewheeling current path is as short as possible to ensure system precision and efficiency
- Power and ground tracks have been maximized around critical areas on both sides to create the intrinsic capacitors for high frequency filtering



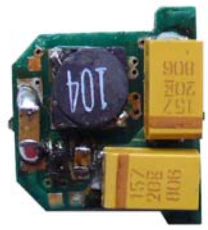
Top copper and silkscreen



Bottom copper and silkscreen

Figure 3 - Circuit layout

Top layer



Bottom layer

Figure 4 - Circuit board views

Quantity	Part reference	Value	Description	Source
1	R1	0.33Ω	Resistor, 1%, 0805	Various
2	C1,C2	150µF/20V	Type D SMD Tantalum Cap	AVX
1	C3	0.1µF/25V	SMD 0805 X7R	NIC Comp AVX
1	C4	1µF/50V	SMD 1210 X7R	NIC Comp AVX
1	C5	1µF/50V	SMD 1206 X7R	NIC Comp AVX
1	C6	0.1µF/50V	SMD 0805 X7R	NIC Comp AVX
1	L1	100µH	MSS6132-104	Coilcraft
3	L2,L3,L4	67Ω@100MHz	744231061	Würth Elektronik
1	U1	ZXLD1350	LED driver IC	Diodes Inc
1	U2	ZXSBMR16PT8	Schottky Bridge rectifier and freewheeling diode	Diodes Inc

Table 1 - Bill of materials

EMC test results for the reference design

Radiated electromagnetic disturbances

The test was performed in accordance with the general lighting standard EN 55015: 2006. The test setup block diagram together with results is shown as below. The radiated emissions from the switching converter can be minimized due to the proper PCB layout, the usage of a screened inductor and the shielding effect of the sealed housing.

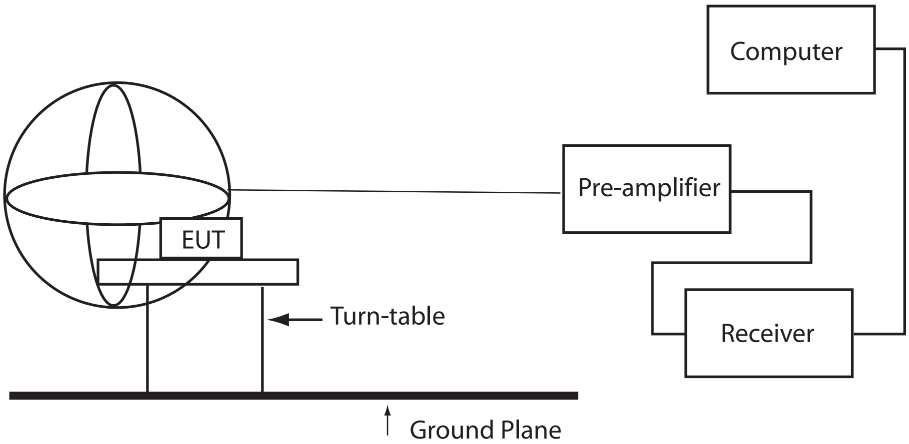


Figure 5 - Block diagram of test setup for radiated electromagnetic disturbances

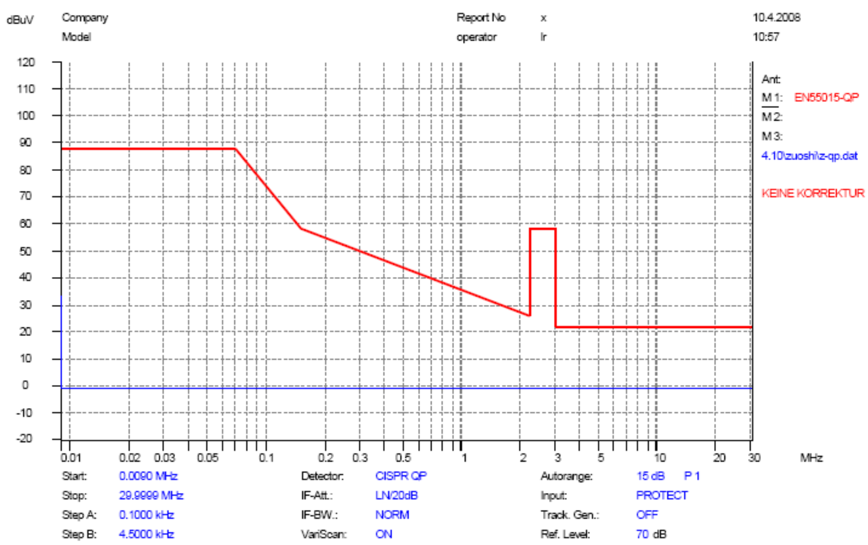


Figure 6 - X direction radiated emission

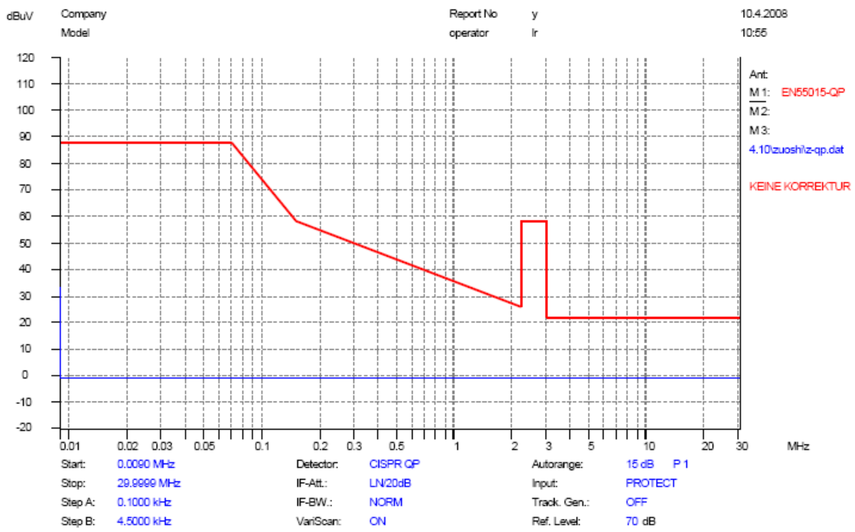


Figure 7 - Y direction radiated emission

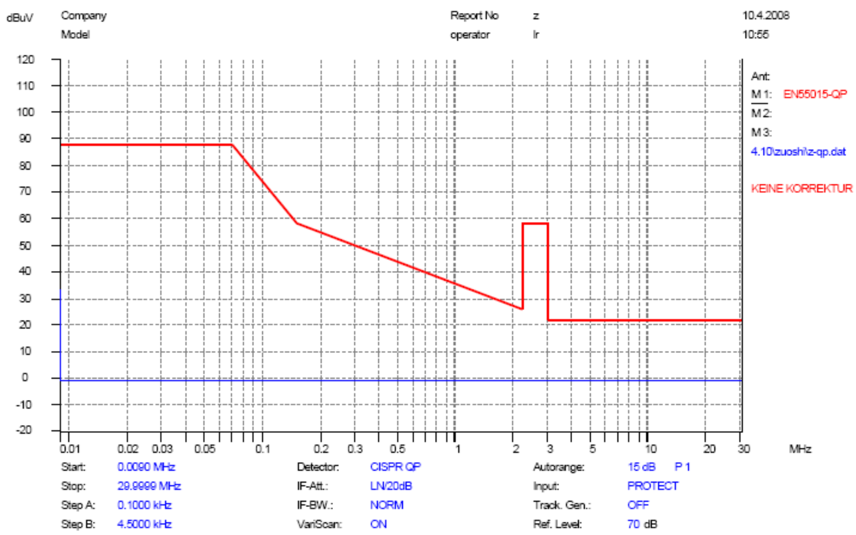


Figure 8 - Z direction radiated emission

Electrostatic discharge

The test was performed in accordance with IEC 61000-4-2 Level B. The EUT was operating normally without shutdown when subjected to ±4kV contact discharge onto the surface of the metallic coated housing while ±8kV air discharge near the insulated input connector. Obviously, the control circuit was not interfered by the ESD with the aid of the housing.

Conducted EMI (optional, customer-driven)

In general, the test is not required under such low input voltage condition. However, it was still performed in accordance with EN 55015 with the special LISN relocation at the 12Vac input terminals to represent a more stringent assessment. The scans with data analysis are shown where the emissions can be suppressed below the limit line by the addition of the input EMI filter with the above mentioned radiated emissions considerations.

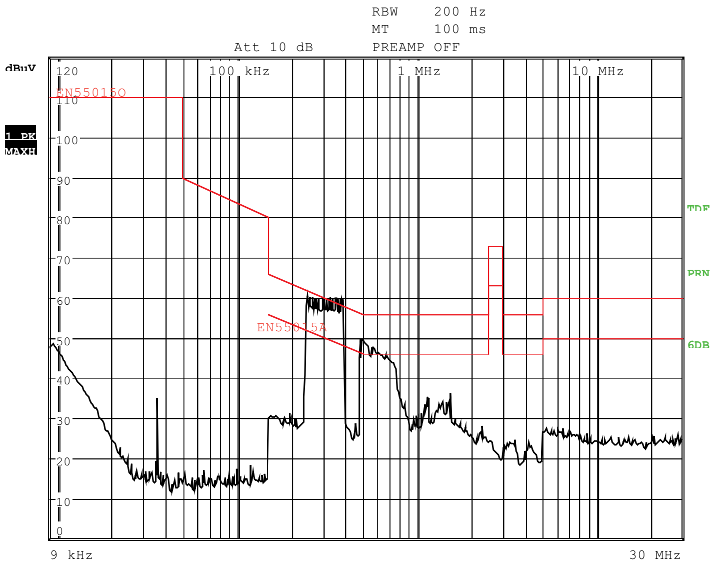


Figure 9 - Live conducted EMI scan

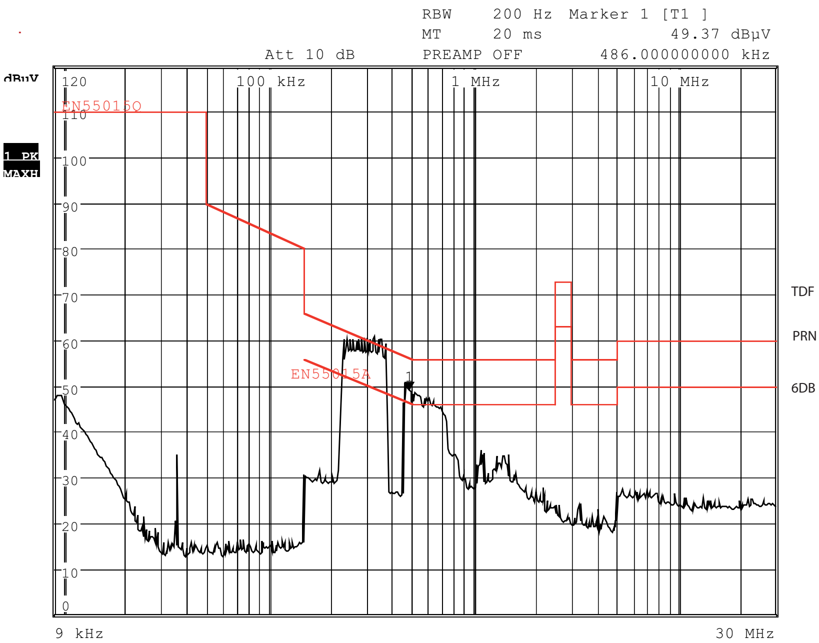


Figure 10 - Neutral conducted EMI scan

Live					Neutral				
Frequency (MHz)	QP (dBµV)		AV (dBµV)		Frequency (MHz)	QP (dBµV)		AV (dBµV)	
	Reading	Limit	Reading	Limit		Reading	Limit	Reading	Limit
0.238	57.6	62.2	36.1	52.2	0.230	55.6	62.4	30.1	52.4
0.290	54.4	60.5	27.5	50.5	0.266	54.8	61.2	27.6	51.2
0.354	55.6	58.9	29.7	48.9	0.310	55.2	60.0	28.1	50.0
0.486	46.5	56.2	26.6	46.2	0.378	33.9	58.3	20.9	48.3
					0.466	42.9	56.6	20.5	46.6

Table 2 - Conducted EMI data record and analysis

Conclusion

A comprehensive EMC compliant reference design is suggested using ZXLD1350, ZXSBMR16PT8, and a few associated passive components for a 3x1W LED MR16 lamp. It features on board EMI filter and low part count. The design exhibits a performance that is excellent in electrical and EMC performance. It can be readily incorporated with a traditional 50/60Hz linear transformer to form a specific EMC compliant lighting system. However, if an electronic transformer is intended to be used, the system EMC compliance level is unknown at this moment. In which case, the EMI filter may need to be re-designed for optimization. The circuit passed a pre-compliance test to the general lighting standard EN 55015: 2006. As with any design, EMC performance is dependent on many factors and users must verify the suitability of their own designs. The purpose of this design note is to show that with careful design and taking advantage of the variable frequency nature of the hysteretic converter an EMC compliant MR16 lamp can be achieved.

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