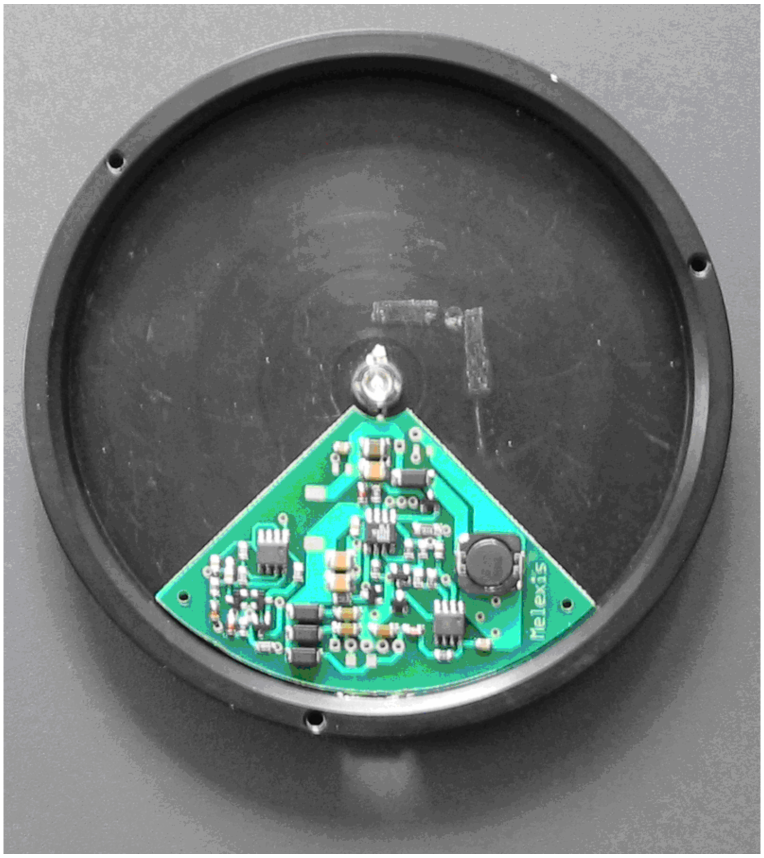
Application note MLX10803

Complex LED driver for CISPR25 class 5

Ultra low noise application example



Melexis's LED driver with 1A current meets requirements Class5 CISPR25

Scope

The document describes how to make a low noise LED driver, using MLX10803.

A combined stop, turn, tail lamp has been selected as an example. The demonstration lamp circuit complies with the American (SAE) automotive standard for a tail light, using one light source for all three functions. This example is similar to many applications currently in use today with LEDs. The applications that exist on the market are using resistor or linear voltage drop regulators, and it will be easy to compare the superior result from this application example with existing products.

Conventional switch regulator IC's do not typically result in circuits that are suitable for use in noise sensitive environments like an automobile. Many competitive, switched Buck topology regulators on the market cannot meet the typical EMC requirements, but MLX10803 and MLX10801 contain features that make it possible to design to an acceptable, low noise level. This document will show to achieve the lowest noise level of CISPR25, class 5.

An engineer who follows the strategies described in this application note should be able you to make good, low noise LED drivers for automotive applications, with good protection at a low cost. Many applications do not need CISPR25 at the highest class 5. You can select to implement the appropriate parts of the design that suit your situation. For more detailed help and information please contact your closest Melexis representative or distributor.

General information about LED drivers.

To convert energy from one voltage and current level to another, energy needs to be switched from one place to another, from one form to another.

Switch regulators move the energy represented by voltage and current, and transform most of the energy to a voltage and current level appropriate for the LED.

In some cases, heat generation or efficiency does not matter. If the supply voltage is higher than needed for the LEDs, the energy difference between the supply voltage and the LED voltage can be dissipated as heat. This is generally done with a linear voltage drop regulator. Linear drop regulators are known not to produce noise, but are inefficient of converting the voltage level. See the energy conversion balance below.

$$\mathbf{V_{Input} \cdot A_{Input} = W_{LED} + W_{Loss}}$$
$$\mathbf{V_{Input} \cdot A_{Input} = V_{LED} \cdot A_{LED} + W_{Loss}}$$
$$\text{Efficiency } [\%] = W_{LED} / (W_{Loss} + W_{LED})$$

$$13.8V \cdot 0.15A = 2.7V \cdot 0.7A + \mathbf{0.18W} \text{ (Heat)}$$

Example 1 Using a high intensity red LED and ***switch regulator.*** *(91% efficiency)*

$$13.8V \cdot 0.7A = 2.7V \cdot 0.7A + \mathbf{7.77W} \text{ (Heat)}$$

Example 2 Using the same high intensity red LED and ***linear drop regulator.*** *(20% efficiency)*
43 times more heat to handle using a linear drop regulator.

From the comparison above it is easy to see that a designer needs 43 times more dissipation capability to cool down the linear LED driver than using a switch regulator. LEDs are also very sensitive to heat. Heat reduces the lifetime of LED significantly. When taking in account the effort required cooling the LED driver, linear LED drivers or voltage drop resistors are not price optimal in many cases compared to switch regulators.

The most important reason to use switch regulator LED driver circuits in automotive applications is the thermal budget.
Switch regulators generate less heat!

PWM modulation effects and noise.

The LED driver circuit described in this application note uses PWM modulation to generate different levels of light output. It is also possible to implement the different levels of brake and tail light by control of the current level. In this respect, there is no difference between a linear drop regulator and a switch regulator.

From the electrical point of view, control of the current level over the LED is preferable. This can in both the linear drop regulator case, and the switch regulator case, be done simply by varying the value of the sense resistor or varying the reference voltage in a suitable way. With MLX10803, this is simply done by changing the value of the resistor connected to the dominating reference input, mostly IREF1. (See MLX10803 IC specification)

From the LED manufacturers point of view a PWM modulation drive scheme is preferable. The production process of LEDs creates LEDs with very different properties of light efficiency. The light efficiency can also vary with different LED currents in different ways. To have control of quality and light output the LEDs are sorted at a given LED current, usually close to the maximum rated current. Despite this sorting, the problem of inconsistent light output reappears when applying lower current level to the sorted LEDs. In addition, the color of the LED can shift slightly with different current and light output. These facts favor a PWM modulation to vary the LED intensity.

A LED in a PWM system is biased to the same current level independent of the resulting light level for the human eye. For tail light, as in our application example, 10% of the time on and for stop light 100%, resulting in 10% and 100% light output.

Be aware! In a PWM system, there can still be an uncontrolled difference in light if the thermal handling is weak. Weak thermal handling can create two different temperature levels for tail and brake light levels resulting in two different light efficiencies. That could give different light outputs than intended by the designer. A temperature compensated LED driver can solve that problem but then are we are back to analog control of the LED current or a complicated feedback control of to the PWM generator must be used.

This issue with different intensity at different currents and temperatures is a known design challenge. LED manufactures are working to improve their product, and LumiLEDs are now offering LEDs for automotive tail light applications tested at two different current level. These LEDs from LumiLEDs then are better suited for current level control of brake and tail functions then many simpler (sorted) LEDs.

As a demonstrator circuit, we chose to apply the electrically more complicated PWM modulation. PWM is more difficult from a noise point of view and more of a design challenge.

PWM modulation creates noise

PWM modulation creates the same type electrical noise if you use a linear drop regulator or switch regulator, the electrical noise of the on and off flanks. If you apply a switch regulator as an LED driver, you probably already have a filter function for step flank. Then you are in a better position with a switch regulator. Note that when using PWM on a linear regulator you might need to apply a noise filter function there as well, and you lose the simplicity of the linear regulator.

One disturbing factor is that the PWM frequency used does mostly need to be in the audible frequency range, creating a huge possibility for audible noise. Resonance in the mechanical build up can be very disturbing. This can actually has even a larger risk to happen with a linear regulator because its higher inefficiency implies use of larger current and result in switching higher energies than when using a switch regulator.

<u>We use PWM in the example not because it is easy but because it is more difficult.</u>

PWM, linear drop regulators and noise

Linear regulators are thought to be without electrical noise and not needing noise reduction filter. This is not always valid when applying PWM to them.

PWM and flicker

We do not recommend use of PWM to modulate the light levels if the LEDs allow you to design with different current levels instead. The Melexis MLX10803 LED driver is well suited for analog level control as well as PWM.

There is a slight potential health risk of a fast flickering light. Compare with the health discussions about flickering lights from CRT screens and using your CRT screen as computer screen. The tail light level in this application will appear as the light from a CRT screen. This is identical to all PWM controlled tail light products that already exist on the streets today using resistor or linear drop voltage regulators as LED current regulators.

When using a PWM controlled LED light source for ambient light, like in interior light applications you can also have strange effects when trying using your (digital) camera in that light. You might see stripes in your pictures as if you was trying to make photos of an old TV screen.

General information about noise.

There are two forms of noise applicable to switch regulators, acoustical and electrical.
Linear regulators can also produce noise if applying a PWM signal, as described in the earlier chapter.

Short note about acoustic noise

The mechanical force the electrical or magnetic field applies on the components generates this type of noise. The electrical field in capacitances and even between components can generate noise. The magnetic field in switch regulators stores most of the energy. This field can make coil windings, core and other parts of the coil vibrate. This type of noise can also appear by applying a PWM function on the LED driver and affects linear regulator as well as switch regulators. Mechanical noise is not good for the lifetime of your application, especially resonance, and should be avoided.

How to treat this acoustical noise mechanically is out of the scope of this article.

Electrical treatment of this audible noise can be useful; Melexis LED drivers use a unique switching technique that allows a randomization of the switching frequency. This prevents some resonance and can result in a lower acoustic noise.

Electrical Noise standards

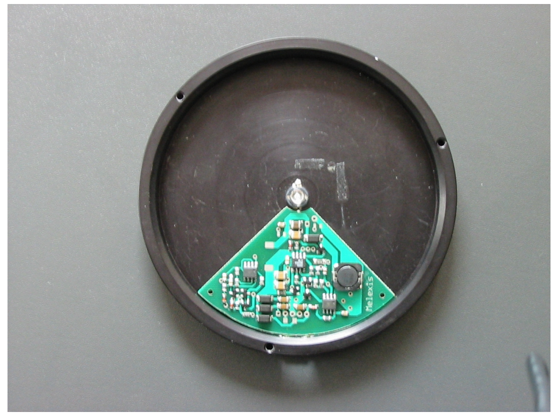
CISPR 25

In the automotive electrical environment there are several tests and test setups to rate the relative noise performance of electronic modules. One commonly used standard and test set up defined by the IEC (International Electrotechnical Committee). The test and test set up is defined under the IEC sub committee, CISPR (an acronym from the French name for the committee known in English as the International Special Committee on Radio Interference). CISPR 25 gives five different reference levels against which to compare your application. Level 1 allows most noise and level 5 allows almost no noise.

IEC 61967

IEC 61967 provides a test procedure, which defines a method for evaluating the near electric, magnetic or electromagnetic field components at or near the surface of an integrated circuit (IC). This diagnostic procedure is intended for IC architectural analysis such as floor planning and power distribution optimization. This test procedure is applicable to measurements from an IC mounted on any circuit board that is accessible to the scanning probe.

Application Example Tail/Turn/Brake Lamp

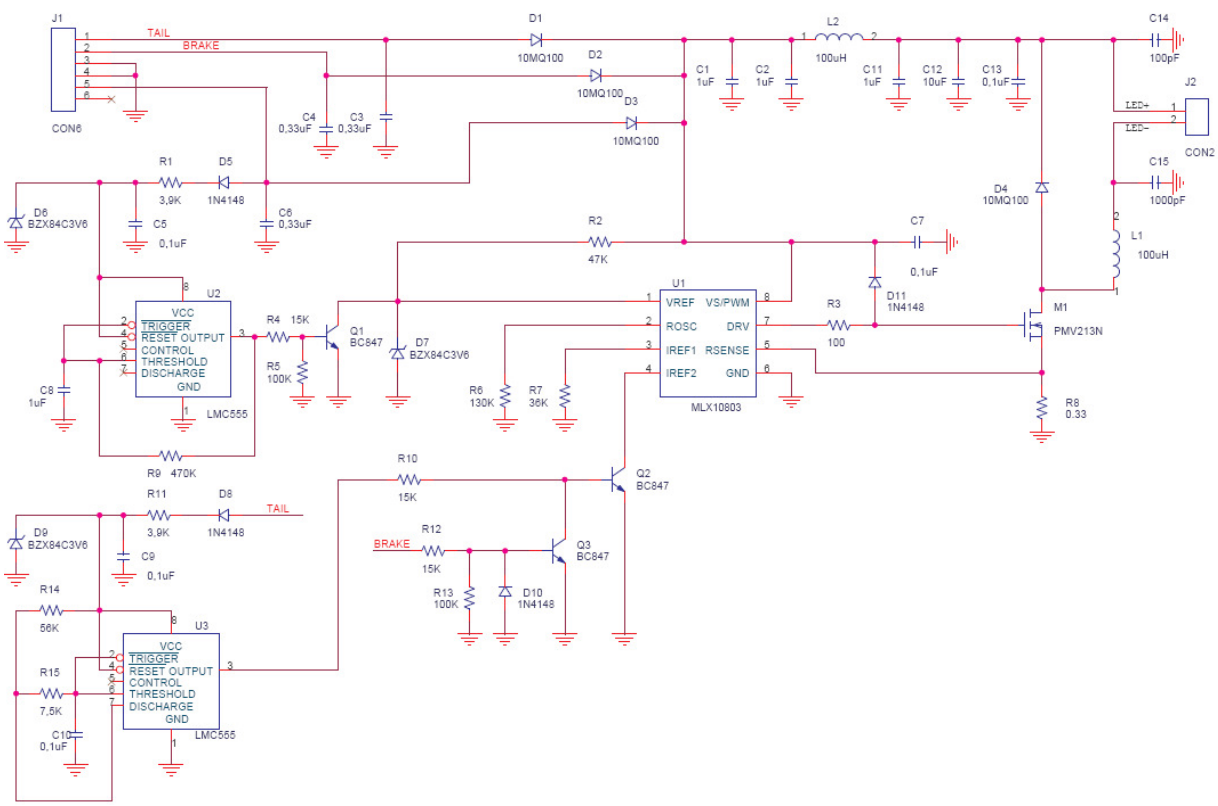


The Lamp is designed to apply to the American standard of tail lamp, including the function of tail, turn and brake light in one red lamp. The LED used is a single red high intensity LED from LumiLEDs.

The circuit can regulate the voltage down from 6 – 30V supply and supplies the LED with a 1000mA current. The Brake function is the full 1000mA over the LED. The Tail light function is a Pulse Width Modulation on this LED current in relation 1:10 – 1:20. A LMC555 circuit creates this PWM function. An additional LMC555 creates in a similar way, but much slower, the Turn signal.

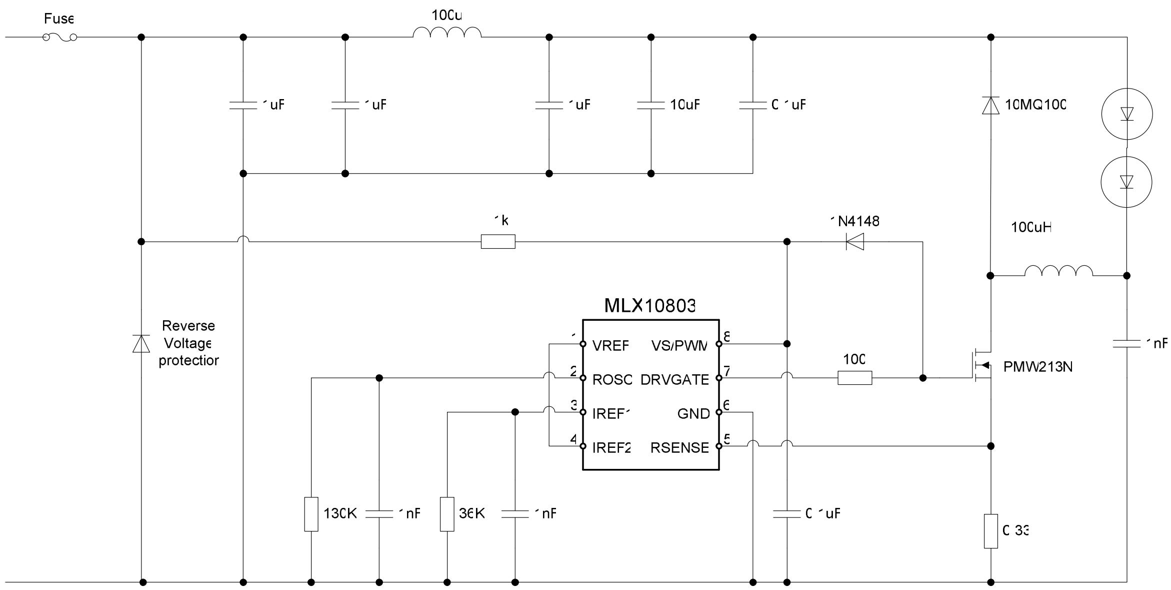
The part of the design that contains the two LMC555 have no influence on the LED driver itself and can be omitted if these functions are not needed.

The application lamp circuit



Schematic 1 The Tail/Turn/Brake lamp circuit

The basic low noise application circuit



Schematic 2 This is the basic circuit used in the application

The circuit above is a good starting point to develop your own low noise LED driver.

External connections to the lamp

The board has 3 inputs: TAIL, BRAKE, TURN and an output for the LED.
Pin assignment for the input and output connectors is provided in Table 1.
The board works according to the truth table, Table 2.
A red LED Luxeon III side emitter is used as a load. The LED is driven to an average current of 1000mA at 100% PWM.

Connector J1	Signal	Connection
Pin 1	TAIL	Control/power supply, 8..16V
Pin 2	BRAKE	Control/power supply, 8..16V
Pin 3	GND	ground
Pin 4	GND	ground
Pin 5	TURN	Control/power supply, 8..16
Connector J2	**Signal**	**Connection**
Pin 1	LED+	LED(s) anode
Pin 2	LED-	LED(s) cathode

Table 1 Pin assignment

BRAKE	TAIL	TURN	CURRENT
0	0	0	0
0	0	1	100% / 0
0	1	0	10%
0	1	1	10% / 0
1	0	0	100%
1	0	1	100% / 0
1	1	0	100%
1	1	1	100% / 0

Table 2 Truth table

Board description

The board contains these subsystems:

- LED driver
- Input filter
- PWM1
- PWM2.

LED driver

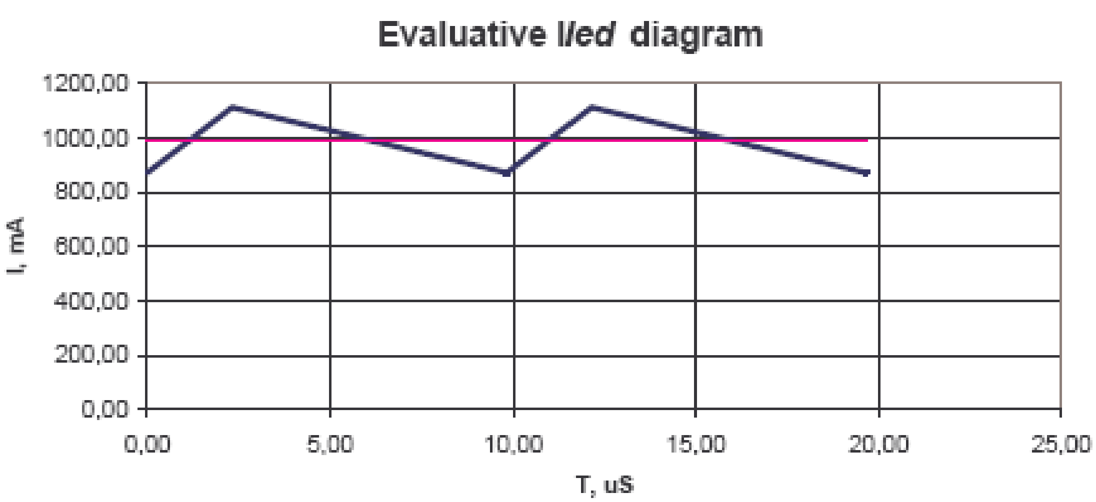
The LED driver uses the MLX10803 chip. The choice of external components as Rosc, Riref, Rsense, determines the mode of switching regulator as well as the value of the LED average current (1000mA). A developer has to take into account such factors as the current tolerance over the input voltage range, the current tolerance vs. tolerance of components and the noise value. The optimal settings can be found using the specially developed spreadsheet tool; Coil Calc. This Excel sheet can be downloaded directly from the Melexis web site. This software helps evaluate the regulator behavior and get desirable values of external components.

The example for how to use Coil Calc in this case:

INPUT DATA	
Supply, V	13
LED threshold, V	2,7
Number of LEDs in chanel	1
Feed back diode threshold, V	0,5
Rsense, Ohm	0,33
Vpeak at Rsense, mV	360
Ipeak, A	1,112
Tmonoflop, uS	7,5
L (the Coil), uH	100

OUTPUT DATA	
The regulation is working	good
Coil's voltage drop	
- during charge, V	10,3
- during discharge, V	3,2
Lowest level of current, A	0,872
Time of discharging to 0, uS	never
Time of charging, uS	2,3
Frequency of switching, kHz	101,7
Average current: LED , A	0,99
Avg. current MLX10801 or FET, A	0,24

MLX10803 ROSC value (kOhm)	128
MLX10803 IREF value (kOhm)	36



Input filter

The board takes the power through the inputs: TAIL, BRAKE, and TURN. The diodes D1, D2, and D3 make the logic “OR” network. In order to meet strong requirements of CISPR 25 level 5 standard, the application must use an input filter. (C1, C2, C11, C12, C13, L2). Additional input capacitors C3, C4, C6, are populated closer to the input connector. Capacitors C14 and C15 reduce the noise level in the FM radio band.

If only a noise level of CISPR 4 and lower is required, this filter can be omitted or reduced.
The total LED current needed has a large influence on generated noise and the design of the noise filter.

PWM1

There are two different ways of controlling LED brightness: analog dimming and digital dimming. The differences and advantage are described in an earlier chapter

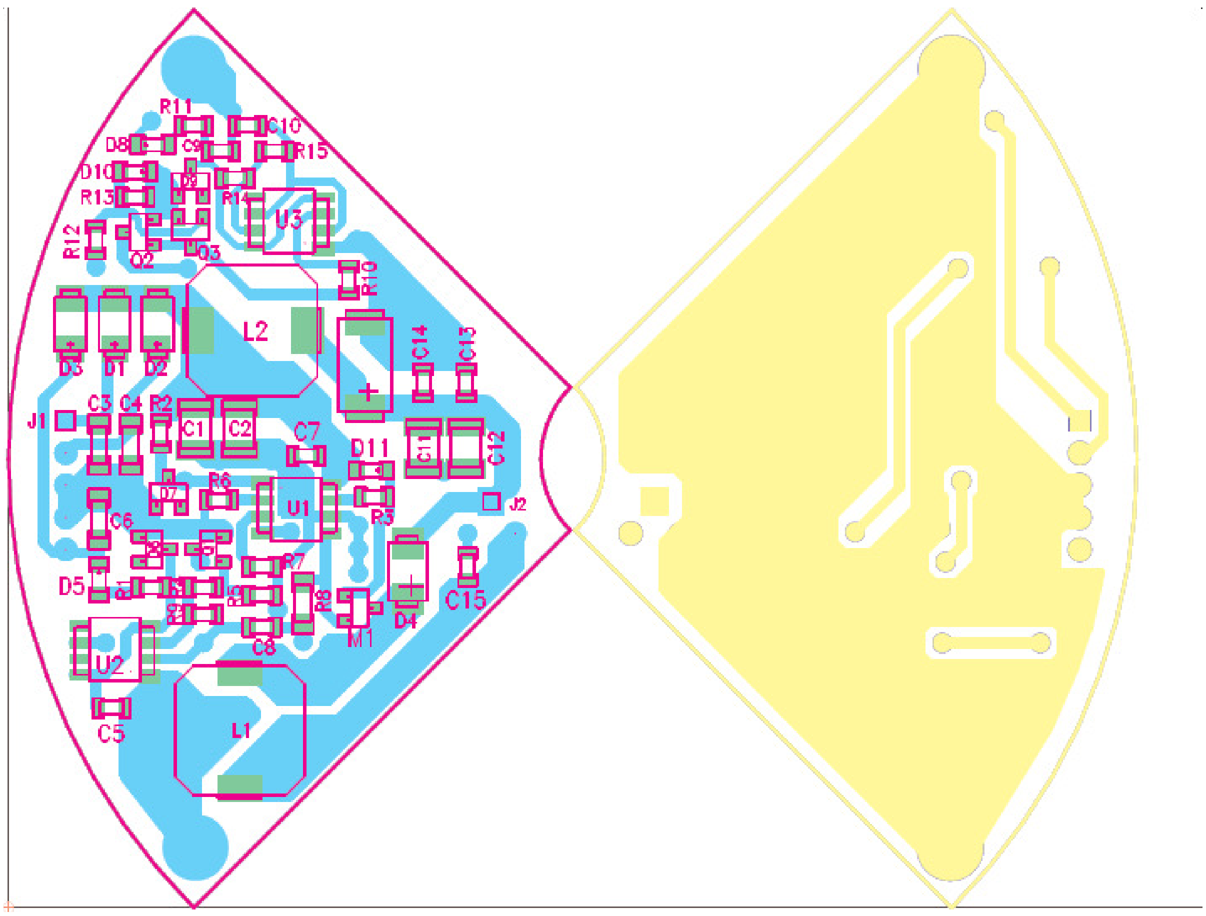
In this board, the desirable level of brightness of 10% from the tail light function arranged by PWM1 module based on the standard 555 timer (U3) with glue components (R14, R15, C10).The timer works as an oscillator with switching frequency 200Hz and duty cycle 10%. The switching frequency, 200Hz avoids visual flicker and minimizes the potential stroboscopic effect a PWM dimming can have. U3 output control, the transistor Q2 and the input IREF2 set the LED’s average current. Additional transistor switch Q3 eliminates influence of PWM1 if voltage is present on the input BRAKE according to requirements in Table 2, “Truth table”.
Diode D10 protects base junction Q3 against negative pulses. U2 gets power from the voltage regulator on the Zener diode D9. Resistor R11 determines the current. In case the input TAIL is faulty connected to a negative voltage, the forward- biased Zener diode alone cannot limit the voltage on the level -0,3V, as the specification for LMC555 require. This is why the additional diode D8 is used.

PWM2 or turn signal generator

One additional LMC555 (U2) provides the blinking function for demonstration purpose. The flash rate is set to 1.5Hz and duty cycle 50% with the components (C8, R9). This second PWM generator switches LED driver on and off through the transistor switch Q1.

PCB Layout

The PC board has two layers and is made from standard FR-4 material with 1mm thickness. It is very important to make a good electrical contact between the PCB and metal case. For this purpose, the holes with metallization are provided on the top and bottom of the board. The board is attached to the metal case by two metal screws, which creates the reliable contact between the board's ground and metal case.



Component List

Ref.	Part	Part Spec.	Package	Manuf.
C1,C2	1uF	X7R,+/-10%,50V	1210	
C3, C4,C6	0,33uF	X7R,+/-10%,50V	1206	
C5, C7, C9, C10	0,1uF	X7R,+/-10%,50V	805	
C8	1uF	X7R,+/-10%,16V	805	
C11	1uF	X7R,+/-10%,50V	1210	
C12	10 uF	X7R,+/-10%,50V	1210	
C13	0,1uF	X7R,+/-10%,50V	805	
C14,C15	100pF	X7R,+/-10%,50V	805	
D1,D2,D3,D4	10MQ100	Shottky diode	SMA	
D5, D8, D10, D11	TS4148	diode	805	
D6,D7,D9	BZX84C3V6	Zener diode	SOT-23	Philips
L1	100uH	CDRH104R-101N		Sumida
L2	100uH	CDRH103R-101N		Sumida
M1	PMV213SN	100V, MOSFET	SOT-23	Philips
Q1,Q2,Q3	BC846A	npn transistor	SOT-23	Philips
R1,R11	3,9K	1/8W,+/- 5%,50V	805	
R2	47K	1/8W,+/- 5%,50V	805	
R3	100	1/8W,+/- 5%,50V	805	
R4,R10,R12	16K	1/8W,+/- 5%,50V	805	
R5, R13	100K	1/8W,+/- 5%,50V	805	
R6	130K	1/8W,+/- 5%,50V	805	
R7	36K	1/8W,+/- 5%,50V	805	
R8	0,33	1/4W,+/- 1%,50V	1206	
R9	470K	1/8W,+/- 5%,50V	805	
R14	56K	1/8W,+/- 5%,50V	805	
R15	7,5K	1/8W,+/- 5%,50V	805	
U1	MLX10803		SO-8	Melexis
U2,U3	ICM7555		SO-8	Philips

Function of Components

Ref.	Part	Function
C1,C2	1uF	Filter capacitances; split in 2, lower the parasitic inductance
C3, C4,C6	0,33uF	Input linedecuopling capacitiance
C5, C7, C9	0.1uF	Input linedecuopling capacitiance
C10	0,1uF	Tail light level generation PWM oscillator capacitance.
C8	1uF	Turn signal generation oscillator capacitance.
C11	1uF	Filter capacitances; split in 3, improves impedance characteristic
C12	10 uF	Filter capacitances; split in 3, improves impedance characteristic
C13	0,1uF	Filter capacitances; split in 3, improves impedance characteristic
C14,C15	100pF	Output noise filter, to LED connection
D1,D2,D3	10MQ100	Function logic and reverse voltage protection
D4	10MQ100	Flyback
D5, D8, D10, D11	TS4148	805
D6,D7,D9	BZX84C3V6	SOT-23
L1	100uH	
L2	100uH	
M1	PMV213SN	SOT-23
Q1,Q2,Q3	BC846A	SOT-23
R1,R11	3,9K	805
R2	47K	805
R3	100	805
R4,R10,R12	16K	805
R5, R13	100K	805
R6	130K	805
R7	36K	805
R8	0,33	1206
R9	470K	805
R14	56K	805
R15	7,5K	805
U1	MLX10803	SO-8
U2,U3	ICM7555	SO-8

Measurement of electromagnetic emission according to CISPR25

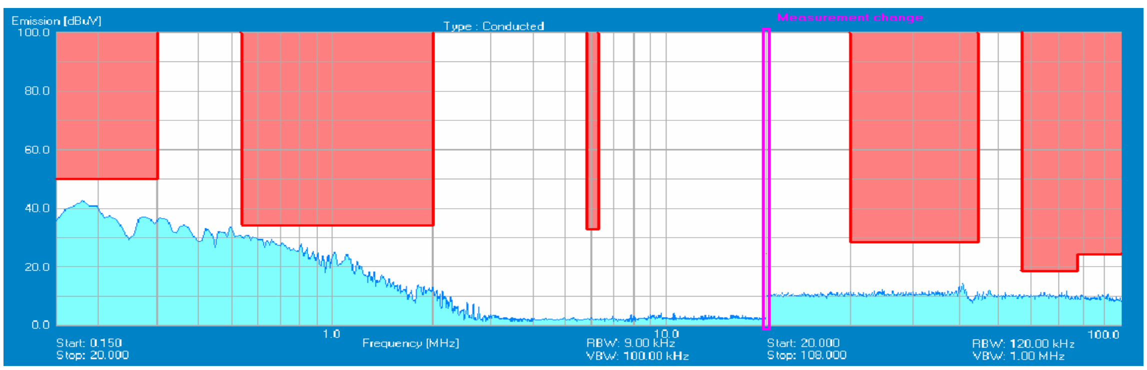
One the most popular EMC standards in the automotive world is the CISPR25, defined by the IEC (International Electrotechnical Committee).. This standard describes the measurement methods for both conducted and radiated emission.

Overview of emission for the board

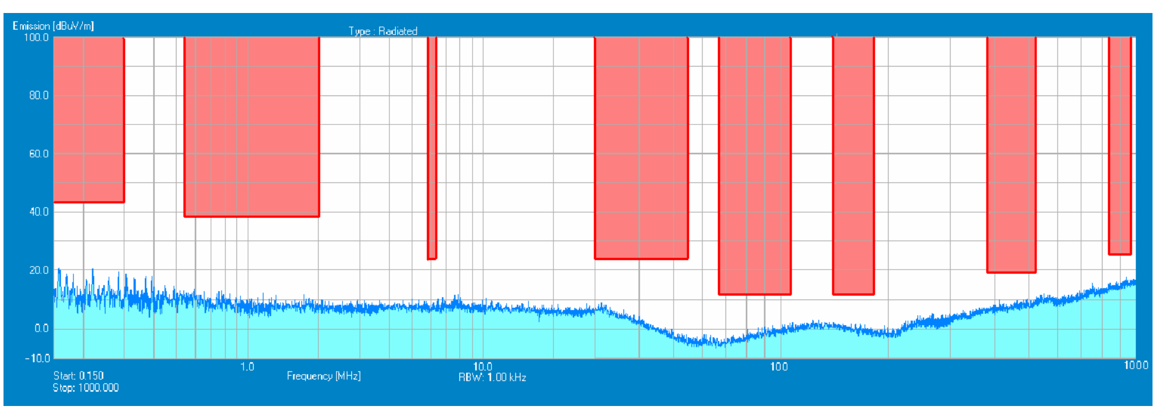
These overview measurements below are with a different version of the application board with slightly different component values. As an example, an increase of the LED current 10 times increases the noise approximately 10dBm. Other selected basic switching frequency moves the curve up or down in frequency. Lower frequency moves the lower part of the curve to lower frequencies, a higher in the opposite direction.

A Melexis customer made the following illustrated measurements of noise on his version of the MLX10803 LED driver circuit. The customer did the measurements independent from Melexis. The measurements demonstrate the excellent results possible with this device in this type of application.

CISPR25 class 5 levels are marked with red.



Conducted emmisions 150kHz – 108MHz



Radiated emmisions 150kHz – 1GHz

Conducted emission measurements

Conducted emission is emission produced by the board on the battery cable. The test bench is described by CISPR25. Power supply voltage is 13,5V.
The standard defines two types of disturbance; broadband and narrowband, and puts separate restrictions for each one. The criteria that determine the type of disturbance is the difference between the peak and average current. A difference lower than 6 dB, defines a narrowband disturbance, a larger difference is considered as a broadband disturbance.

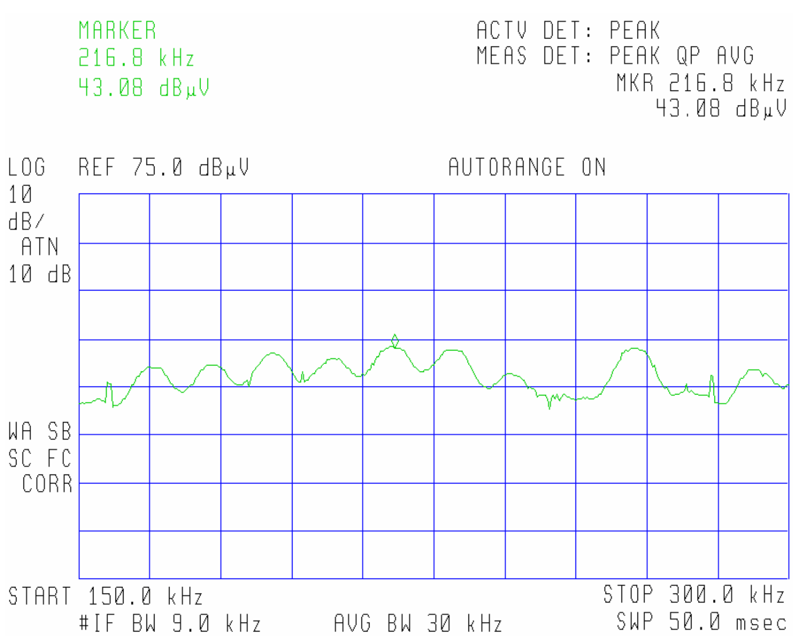
The result of this measurement allows making the conclusion that for conducted emission the disturbance has the narrowband nature.

The Table 7 from CISPR25 determines the Classes of Equipment.

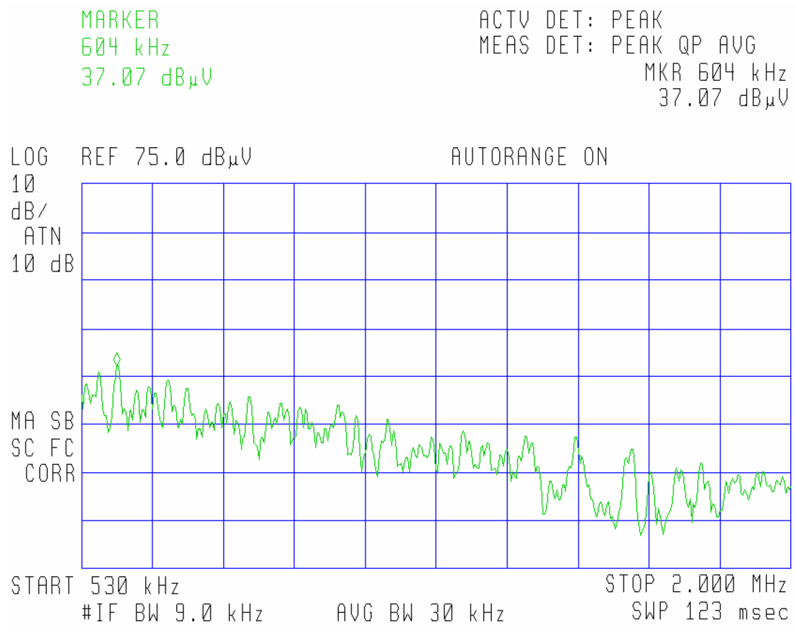
Table 7 (from CISPR 25) – Limits for narrowband conducted disturbances (Peak detector)

Class	Levels dB(µV)					
	0.15MHz to 0.3 MHz	0.53 MHz to 2.0 MHz	5.9 MHz to 6.2 MHz	30 MHz to 54 MHz	68 MHz to 87 MHz	76 MHz to 108 MHz
1	90	66	57	52	42	48
2	80	58	51	46	36	42
3	70	50	45	40	30	36
4	60	42	39	34	24	30
5	50	34	33	28	18	24

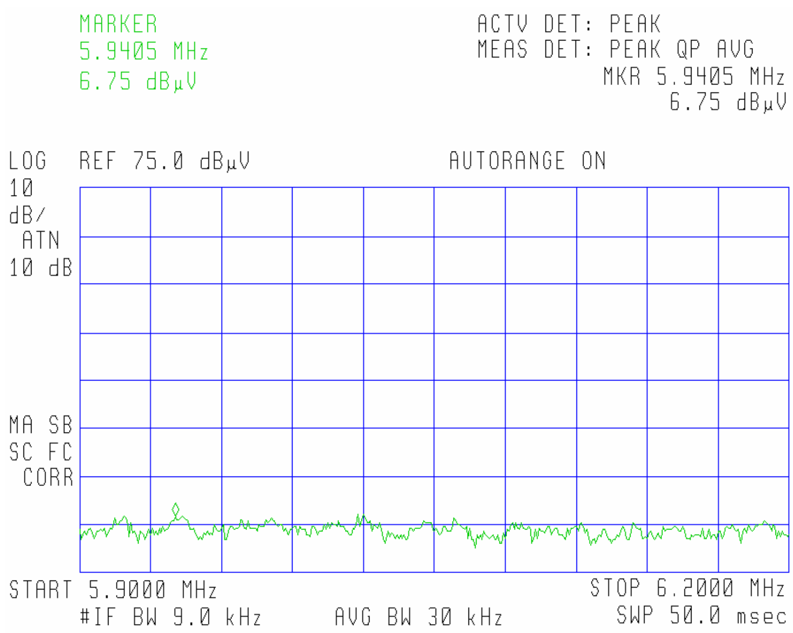
Table 3 (Table 7 from CISPR 25)



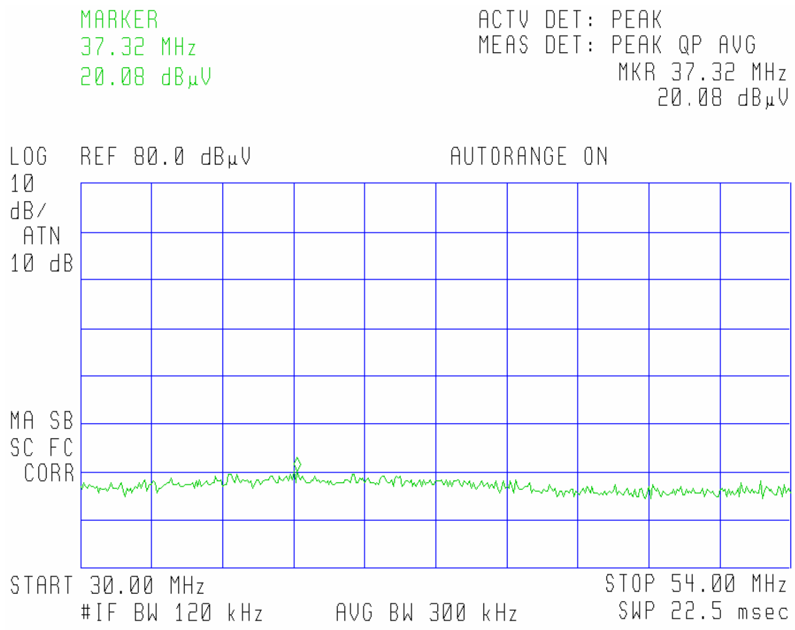
Result for the bandwidth 0,15MHz to 0,3MHz



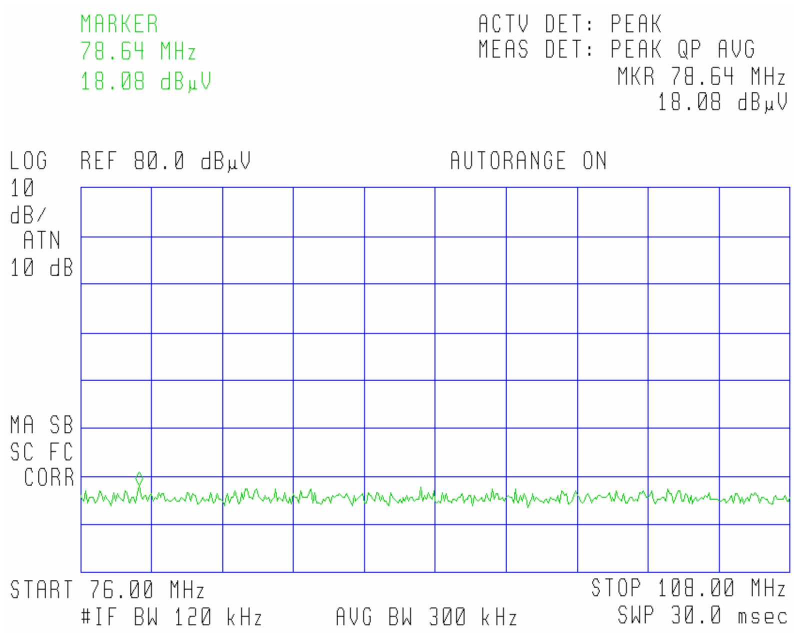
Result for bandwidth 0,53MHz to 2MHz



Result for the bandwidth 5,9MHz to 6,2MHz



Result for the bandwidth 30MHz to 54MHz



Result for the bandwidth 76MHz to 108MHz

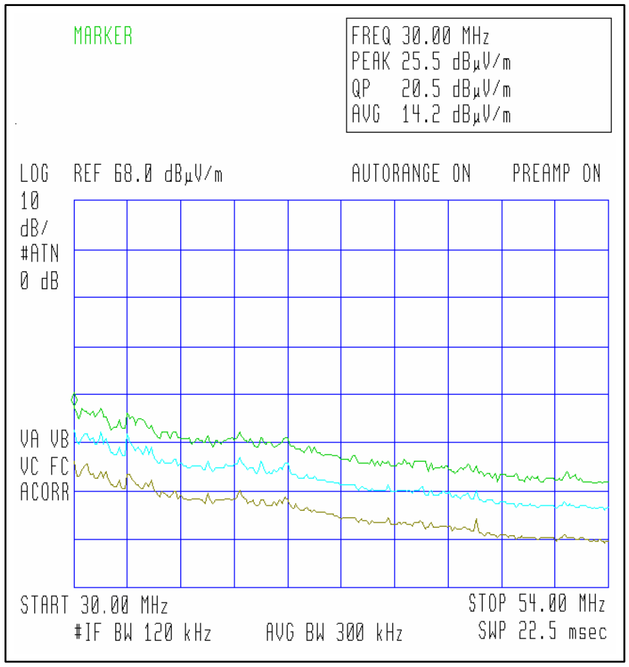
The results represented above allow asserting that the board meets the requirements of Class 5.

Radiated emission measurements

The radiated emission consists of measuring electromagnetic radiation produced by the board. CISPR25 gives the schematic test bench. To measure radiated emission at all frequency ranges requires the use of several different antenna types.

- 0.15MHz to 30MHz: 1 m vertical monopole in vertical polarization
- 30MHz to 200MHz: a biconical antenna used in vertical and horizontal polarization.
- 200MHz to 1000MHz: log-periodic antenna used in vertical and horizontal polarization.

Due to absence of monopole, only last two antennas were used. In order to determine the type of disturbance the next measurement has been made.



The difference between peak and average for both vertical and horizontal polarization is 12dB over the range. It means that the board generates broadband radiated emission. CISPR25 determines the next restriction for this case.

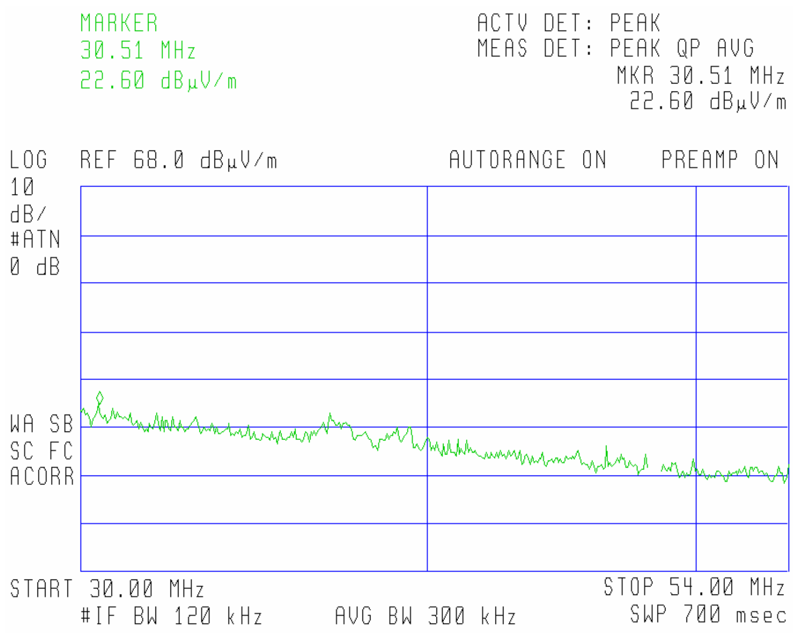
Table 10 (from CISPR 25) – Limits for broadband radiated disturbances (peak or quasi-peak detector)

Class	Levels dB(µV)															
	0.15MHz to 0.3 MHz		0.53 MHz to 2.0 MHz		5.9 MHz to 6.2 MHz		30 MHz to 54 MHz		68 MHz to 108 MHz		142 MHz to 175 MHz		380 MHz to 512 MHz		820 MHz to 960 MHz	
	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]	P[a]	QP[b]
1	96	83	83	70	60	47	60	47	49	35	49	35	56	43	62	49
2	86	73	75	62	54	41	54	41	43	30	43	30	50	37	56	43
3	76	63	67	54	48	35	48	35	37	24	37	24	44	31	50	37
4	66	53	59	46	42	29	42	29	31	18	31	18	38	25	44	31
5	56	43	51	38	36	23	36	23	25	12	25	12	32	19	38	25

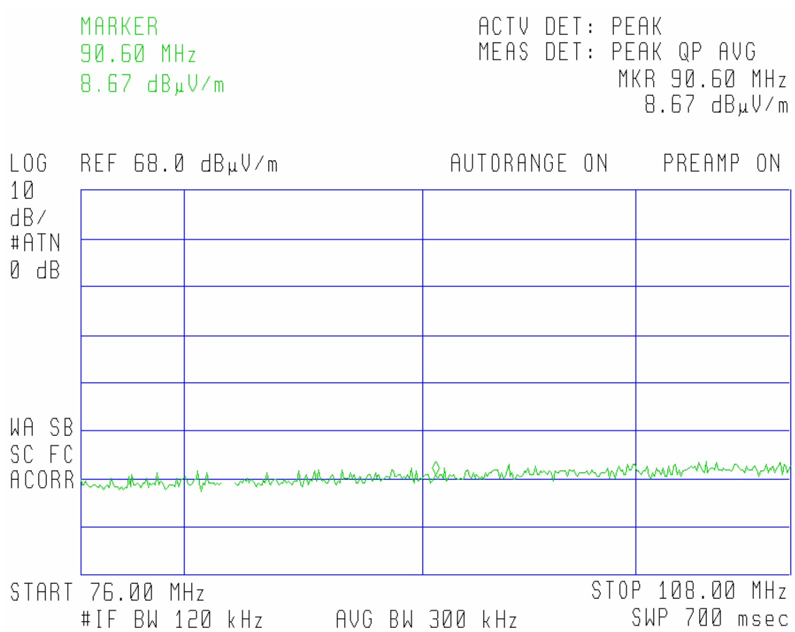
[a] Peak
[b] Quasi-peak

The results of measurement of radiated emission for the board

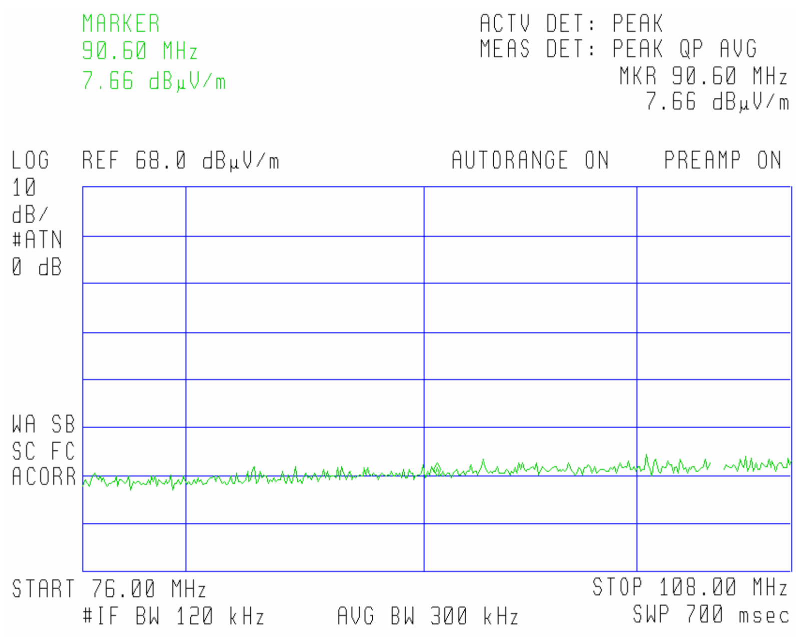
HORIZONTAL POLARIZATION



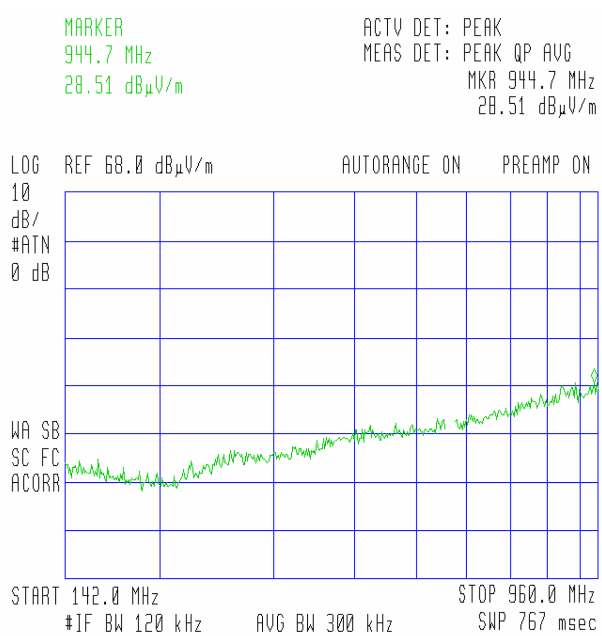
Result for bandwidth 30 – 54MHz



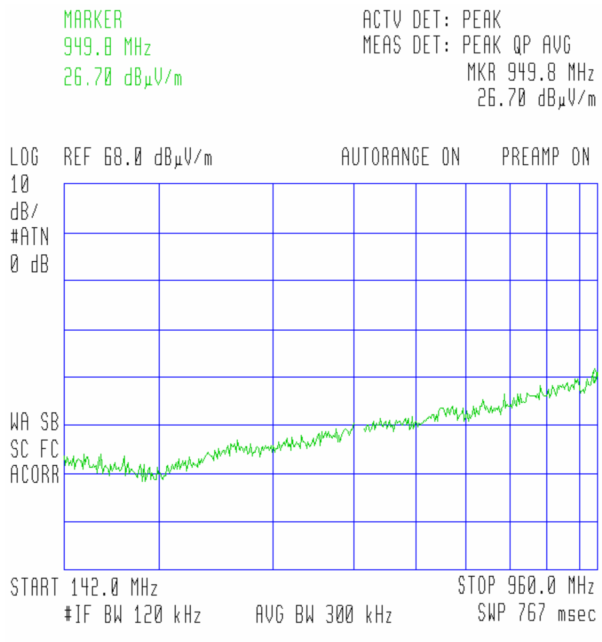
This picture provides result of environment noise measurement when board is turn off (so called OUT OF SIGNAL) in the range 76-108MHz.



Results for bandwidth 76 – 108MHz



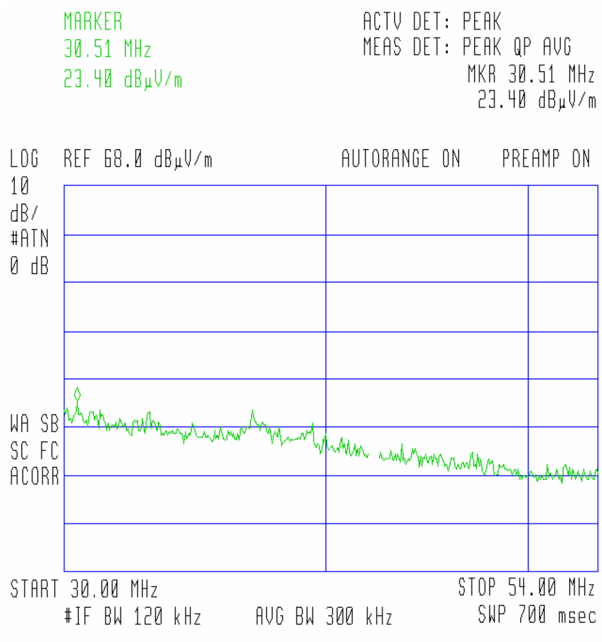
OUT OF SIGNAL for 120 – 960MHz.



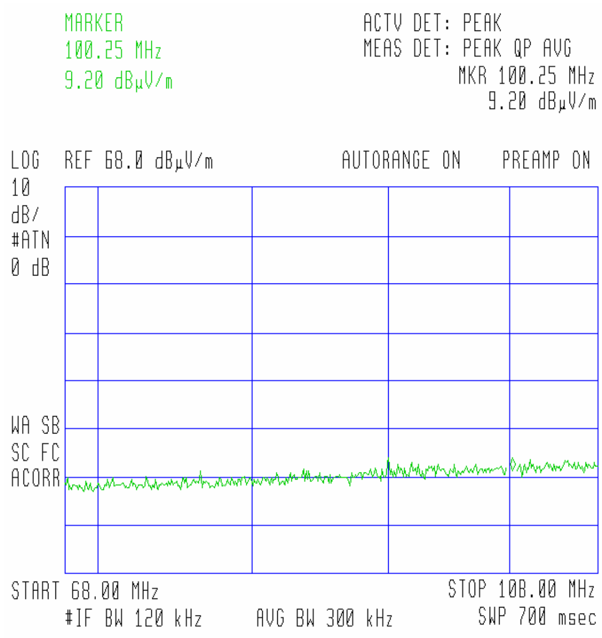
Result for bandwidth 120 – 960MHz

VERTICAL POLARIZATION

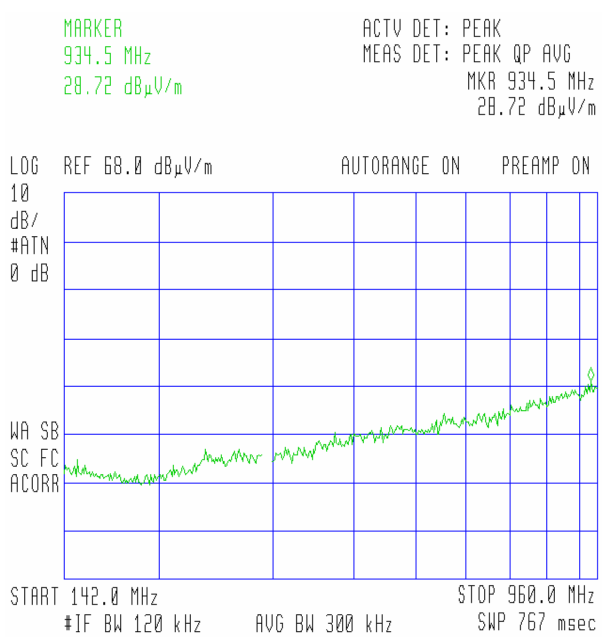
The results for antenna with vertical polarization is quite similar as for horizontal polarization
It was not of any significant difference between OUT OF SIGNAL results and results when board was turn on.



Results for bandwidth 30 – 54MHz



Results for bandwidth 76 – 108MHz



Result for bandwidth 120 – 960MHz

Conclusion

This application note shows the advantage of using Melexis LED drivers to create a low noise application for large LED currents and gives guidance on selecting the correct components and design.

In addition to the noise requirement, you have to take care of selecting robust and useful components of high quality. By selecting Melexis components for your design, you can always be sure that you select the best automotive quality ICs.

We at Melexis are very interested to hear your opinion and can assist you in customizing a circuit example for your automotive applications. There are also more things that can make your design a winner. Things like LIN interface and additional sensors.
Small things make a big difference.

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