AL8862Q

Input Filter Design for CISPR 25 Compliance

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Diodes Incorporated Buck LED drivers, AL8860Q, AL8861Q and AL8862Q, provide low-cost and robust solutions for driving high-current LEDs in interior and exterior automotive lighting applications. The flexibility, owing to their hysteretic control scheme and adjustable frequency, enables designers to minimize overall system size and cost.

This design example uses the standard AL8862QEV1 evaluation board as shown in Figure 1. This board is designed to demonstrate and evaluate the AL8862Q in an SO-8EP package for applications such as headlights and taillights. This board was not optimised to pass CISPR 25 automotive EMC standard. This application note discusses the input filter(s) that need to be implemented in order to ensure that the design passes CISPR 25 Class 4 conducted emissions while optimizing board space and system efficiency.

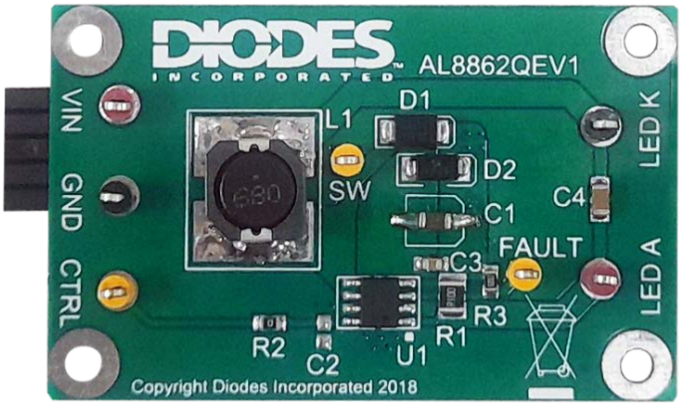

Figure 1: AL8862QEV1

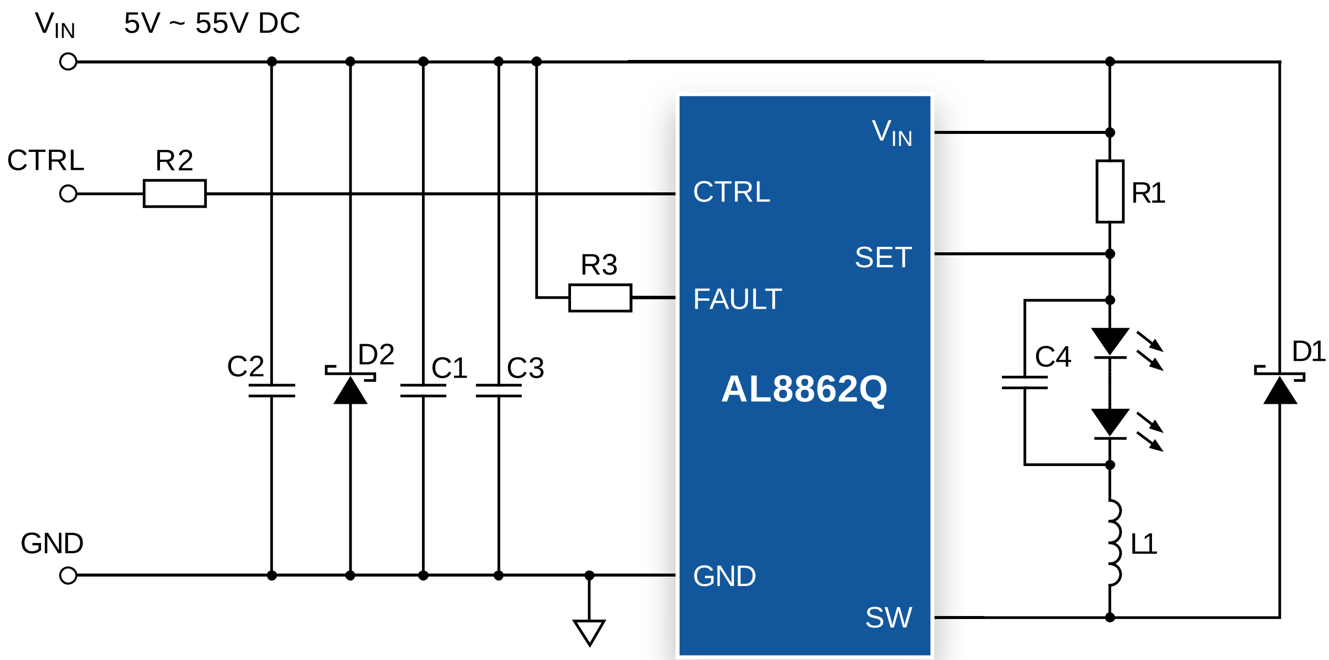

Figure 2: AL8862QEV1 Schematic

Procedure for Input Filter Design:

For details on the LED converter implementation, please refer to the datasheet of AL8862Q. The filter design is dependent on the selection of values for C_{f1} and L_f. C_{f2} is optional but may be necessary to provide damping to avoid instability in the filter.

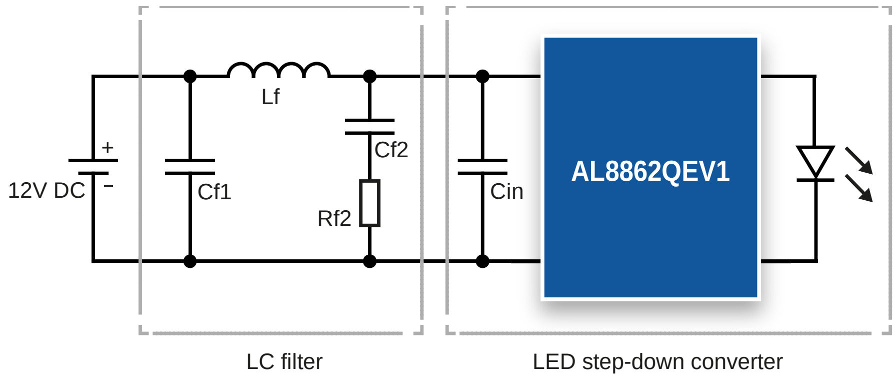

Figure 3: Input LC filter cascaded with an LED driver based on AL8862Q DC-DC converter.

Steps in Filter Design:

Step 1. Select C_{in} according to AL8862Q datasheet.

Step 2. Measure the noise across the CISPR 25 frequency range.

Step 3. Determine filter attenuation based on the noise and target CISPR 25 limits.

Step 4. Select L_f according to methodology below.

Step 5. Calculate C_{f1} according to methodology below.

Step 6: Selection of C_{f2} and R_{f2}. It is also important to consider the damping of the filter. High Q filters can be prone to instability with switching loads.

Note: this filter is not effective at reducing common mode (CM) noise on input lines if CM noise exists.

Input Capacitor Selection (C_{in}):

The input supply to the AL8862Q must be decoupled to ground with a low ESR ceramic capacitor (X7R recommended) immediately next to the VIN pin. The input ripple voltage amplitude is directly proportional to the LED load current. To determine a suitable size for the input capacitor, the following equation can be used.

$$C_{in(min)} = \frac{D \times (1-D) \times I_{LED}}{V_{pk-pk(ripple)} \times f_{sw}}$$

Where:

$C_{in(min)}$ (F) is the recommended minimum input capacitance for the DC-DC LED converter.

f_{sw} (Hz) is the switching frequency of the DC-DC LED driver.

I_{LED} (A) is the average LED output current.

$V_{pk-pk(ripple)}$ (V) is the peak-to-peak ripple voltage at the input. With 9.4µF input capacitance and 0.54 duty cycle it is typically 150mV.

D is the duty cycle of the step-down DC-DC LED converter. The duty cycle can be approximated using the Equation below with an estimated diode forward voltage ($V_f = 0.5V$) and the LED driver internal MOSFET on-resistance ($R_{DS(on)} = 0.4\ \Omega$).

$$D = \frac{V_{out} + R_{DS(on)} I_{LED}}{V_{in} - V_F + R_{DS(on)} I_{LED}}$$

An input capacitance of 9.4µF (2 x 4.7µF) is utilised in the AL8862QEV1.

EMI Noise Estimation for Required Attenuation:

Using the Spectrum Analyser and Line Impedance Stabilization Network (LISN)

The conducted emissions can directly be measured in dBμV using a spectrum analyser and LISN. A LISN is an industrial instrument that creates an 'artificial network' and is intended to be installed between the EUT's power source and input.

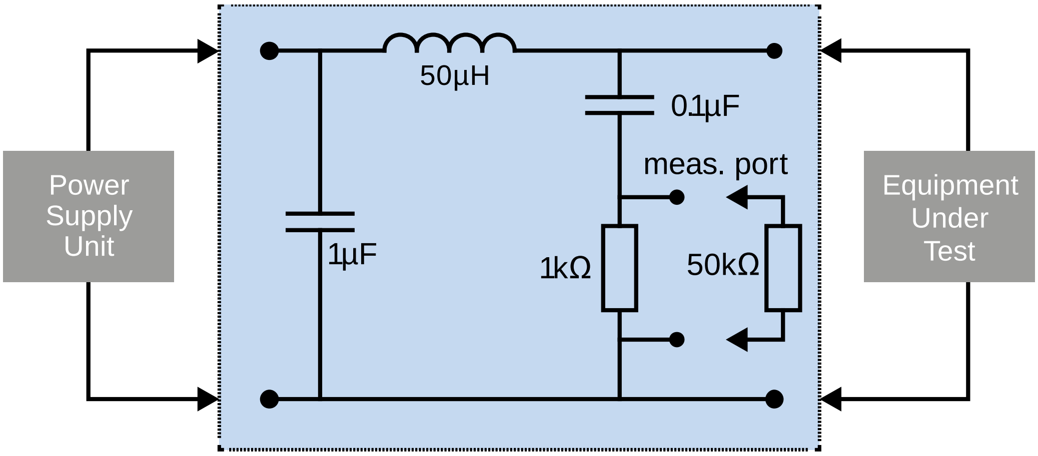

Figure 4: Internal circuit diagram of Las per the CISPR 25 automotive standard

Component Selection:

Example operating conditions are given in table 1:

PARAMETER	COMMENTS	SPECIFICATION
V_{in}	Automotive batteries' nominal operating voltage	13.5V DC
V_{out}	Total voltage across the LED chain anode to cathode (2x LEDs in series)	7.15V DC
I_{LED}	Average output current to the LEDs	1A
C_{in}	Input capacitance of the LED Driver	9.5μF (2×4.7μF+0.1μF)
f_{sw}	Switching frequency of the AL8862Q under nominal operating conditions	175kHz

Table 1: Example Operating Conditions

CISPR 25 Sweep to Get Values for Required Attenuation.

The magnitude of the attenuation level has been measured by using the spectrum analyser and LISN circuit. The measured EMI are shown in the plot obtained from the spectrum analyser below:

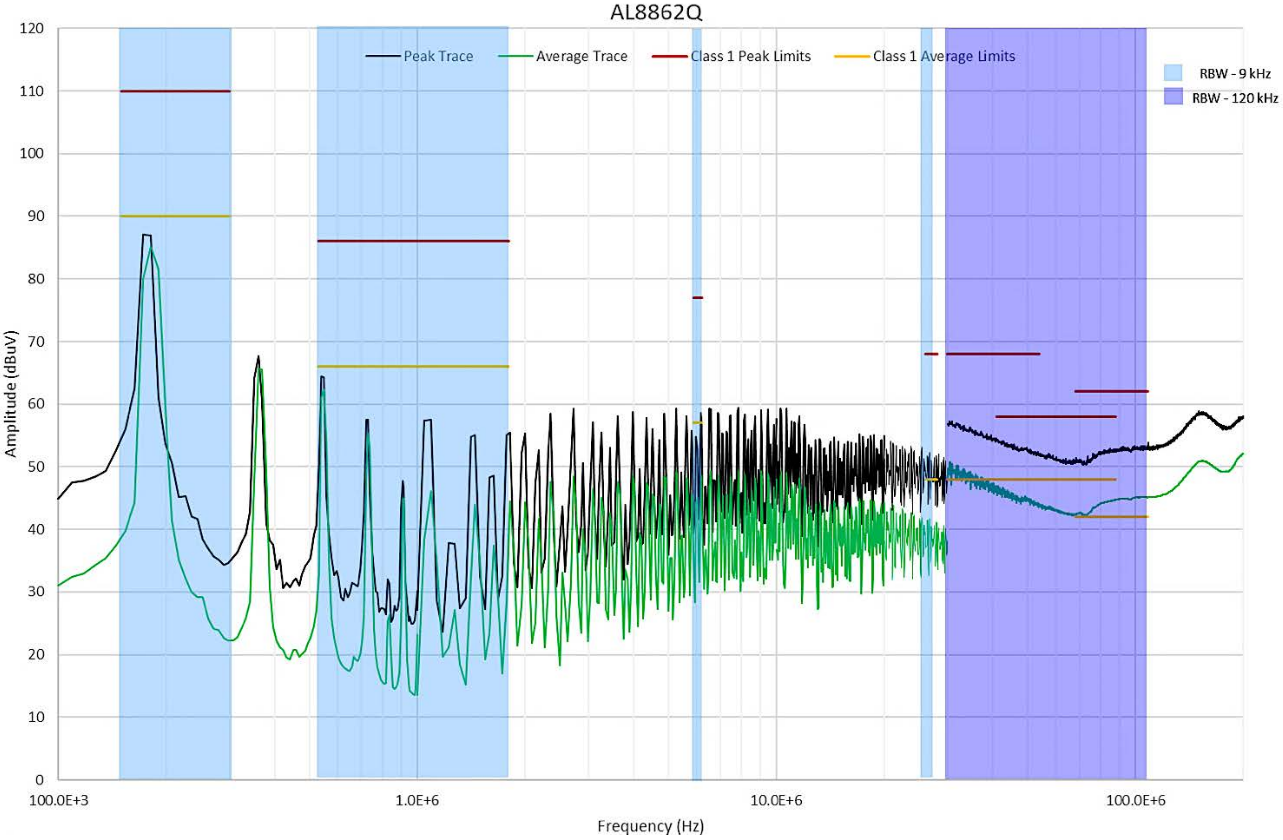

Figure 5: Plot obtained from spectrum analyser

The EMI peak, which occurs at the fundamental frequency is 88 dBµV. The AL8862Q is not complaint to any CISPR 25 class.

Determine Filter Attenuation Based on the Noise and Target CISPR 25 Limits.

The fundamental frequency of the conducted noise is at the switching frequency of the LED driver. While higher-order harmonics will appear, the EMI at the fundamental (assuming within a CISPR 25 band) typically requires attenuation with additional input filtering to meet requirements. The LC filter is a single stage differential-mode filter with attenuation slope of -40 dB/decade (i.e., one inductor and one capacitor). This low component count makes this filter highly cost effective and efficient.

The safety Margin (dBµV) is chosen for the required attenuation and can be set to 20dB in a conservative case.

The largest peak in the sweep occurs at approximately 175kHz and is at 88dBµV, so we need to target this frequency and therefore our attenuation calculation is going to be based on this value.

The target filter attenuation required to meet CISPR 25 class 4, 80dBµV at this frequency, with a 20dBµV safety margin is calculated using equation:

$$Attenuation(dB\mu V) = Amplitude(dB\mu V) - CISPR\ LIMIT(dB\mu V) + SafetyMargin\ (dB\mu V)$$

$$Attenuation(dB\mu V) = 88 - (80) + 20 = \mathbf{28}\ (dB\mu V)$$

Selection of Filter Inductor (L_f)

For low to medium power LED applications, a suitable range for inductor values is from 0.68µH to 22µH. The filter inductor value is inversely proportional to the filter capacitor value i.e., for high rating of inductor, filter capacitor will be a low value and vice versa. The selected value of inductor is 22µH to reduce capacitance value and current ripple.

Selection of Filter Capacitor (C_{f1})

The capacitor value is estimated using equation:

$$C_{f1} = \frac{1}{L_f(2\pi f_r)^2 - 1}$$

Where f_r is $\frac{f_{sw}}{10}$.

In this case we get:

$$C_{f1} = \frac{1}{22 \times 10^{-6}(2 \times 3.14 \times 17.5 \times 10^3)^2 - 1}$$

$$C_{f1} = 3.76\ \mu F$$

The capacitor can also be calculated by using equation:

$$C_{f1} = \frac{\left(10^{Attn/40}\right)^2}{L_f(2\pi f_{sw})^2}$$

In this case we get:

$$C_{f1} = \frac{\left(10^{28/40}\right)^2}{22 \times 10^{-6}(2 \times 3.14 \times 175 \times 10^3)^2}$$

$$C_{f1} = \frac{25.11}{22 \times 1.2 \times 10^6} = 0.95\ \mu F$$

To satisfy both conditions, the higher value of capacitance must be selected. The selected component value is therefore 4.7uF as it is the nearest standard value.

Selection of C_{f2} and R_{f2}

These are the damping components used to reduce the resonant peak of the input filter. A damping capacitor is highly sensitive to the ESL of the inductor as this is the major contributor to the damping of Q in an LC filter. An electrolytic capacitor C_{f2} can also be used to reduce high output impedance at the resonant frequency. The damping capacitor and resistor are calculated as:

$$C_{f2} \geq 4 * C_{in}$$

$$R_{f2} = \sqrt{\frac{L_f}{C_{f1}}}$$

Test Results with Example Operating Conditions

PARAMETER	COMMENTS	SPECIFICATION
V_{ripple}	Peak noise level	88 dBμV
$V_{ripple(CISPR)}$	Target noise level based on CISPR 25 Limit for Class 4 CE (with additional safety margin)	80 (target) – 20 (safety) = 68-dBμV
$Attn$	Required attenuation to meet target noise level	28-dB
L_f	Selected LC filter inductance	22-μH
C_{f1} (calc)	Calculated LC filter capacitance	3.76μF
C_{f1}	Selected LC filter capacitance	4.7μF
C_{f2}	Selected damping capacitance	0μF

Table 2: Parameters for an undamped LC input filter design

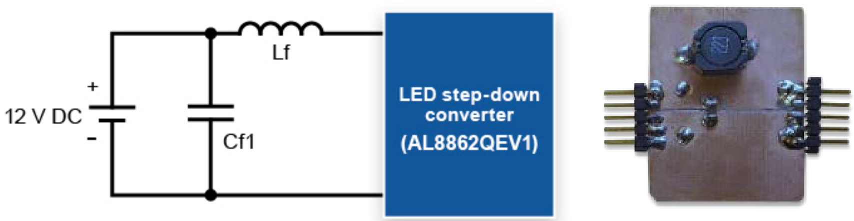

Figure 6: Undamped LC filter (a) block diagram with LED driver circuit (b) photo of the designed filter

The plot obtained using the filter under the above test conditions:

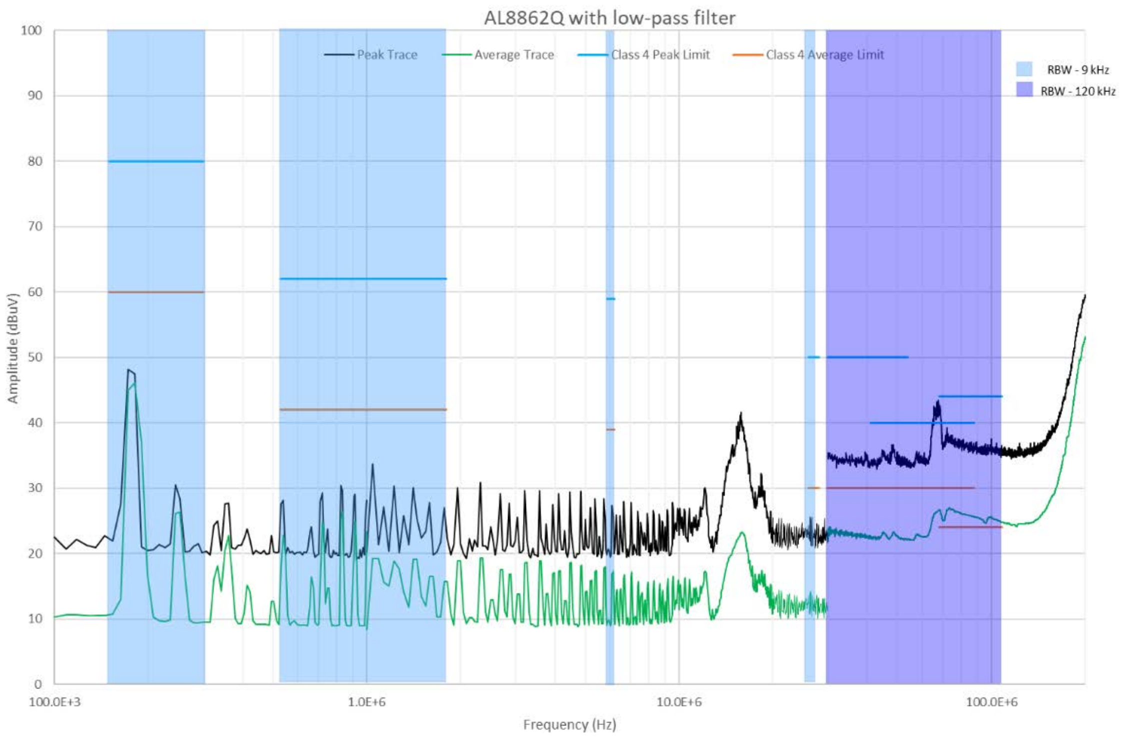

Figure 7: AL8862QEV1 with undamped LC filter, 13.5V In, 1A output current, 100 kHz – 200 MHz.

The magnitude of the attenuation level has reduced significantly from 91dBµV to 48dBµV, an attenuation of 43 dBµV, after adding the undamped LC filter to the LED driver circuit. This passes CISPR 25 class 3 limits confidently and fails Class 4 at frequencies greater than 40 MHz.

High Frequency Attenuation

The previous input filter is great at attenuating the lower frequencies that were causing issues, as well as attenuating differential-mode noise. However, the filter does not do a good enough job at attenuating high frequencies and does not attenuate common-mode noise at all. To help with this, a simple common-mode choke pi filter can be used to attenuate high frequencies, attenuate common-mode noise, and achieve a class 4 pass.

Shown below is a typical common-mode Pi filter. In this use case it is a simple filter with a common mode choke and two capacitors on either side.

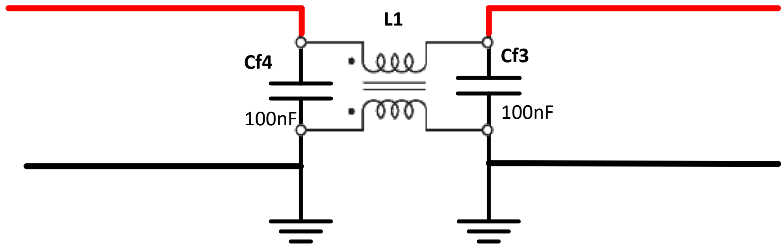

Figure 8: Common-mode Pi Filter Design

Component Selection:

The 2 components needed are:

- Capacitors (C_{f3} and C_{f4})
- Common-mode choke

The choice of the common-mode choke is dictated by the required attenuation frequency/frequency range and the attenuation at said frequency/frequency range. A higher impendence (Z, in Ω) indicates higher attenuation.

For example, for the AL8862Q, the high frequency noise problem occurs at approximately 40MHz and above. Therefore, it is best to select a common-mode choke that has a maximum impedance at anything from 40-100 MHz, and appropriate current and voltage ratings must be observed.

The Bourns SRF7035A-102Y was chosen. This part has a maximum $Z_{(differential)}$ of 1300Ω @ 100MHz. It also has a maximum $Z_{(common\text{-}mode)}$ of 1000Ω @100MHz.

To find the correct values for the capacitors, use the equation:

$$f_c = \frac{1}{2\pi\sqrt{L_{CM\ Choke} C_{pi}}}$$

$$C_{pi} = \frac{1}{4\pi^2 L {f_c}^2}$$

Where f_c is the desired cutoff frequency, $L_{CM\ Choke}$ is the inductance of the common-mode choke (available on the datasheet) and C_{pi} is the desired capacitance value. Tuning the capacitance will, by nature, alter the cutoff frequency of the common-mode choke Pi filter.

As the low pass filter is in series, to account for this simply add the capacitance value C_{f1} to the equation like so:

$$f_c = \frac{1}{2\pi\sqrt{L_{CM\ Choke}(C_{pi} + C_{f1})}}$$

$$C_{pi} + C_{f1} = \frac{1}{4\pi^2 L f_c^{\ 2}}$$

100nF have been chosen capacitors as they give us a cutoff frequency of approximately 26kHz. This means that the common-mode pi filter will also help with the low-frequency filtering.

Note: although the common-mode choke has a resonant frequency that amplifies the fundamental switching frequency slightly, it still has a net positive effect.

This setup produced the results shown below:

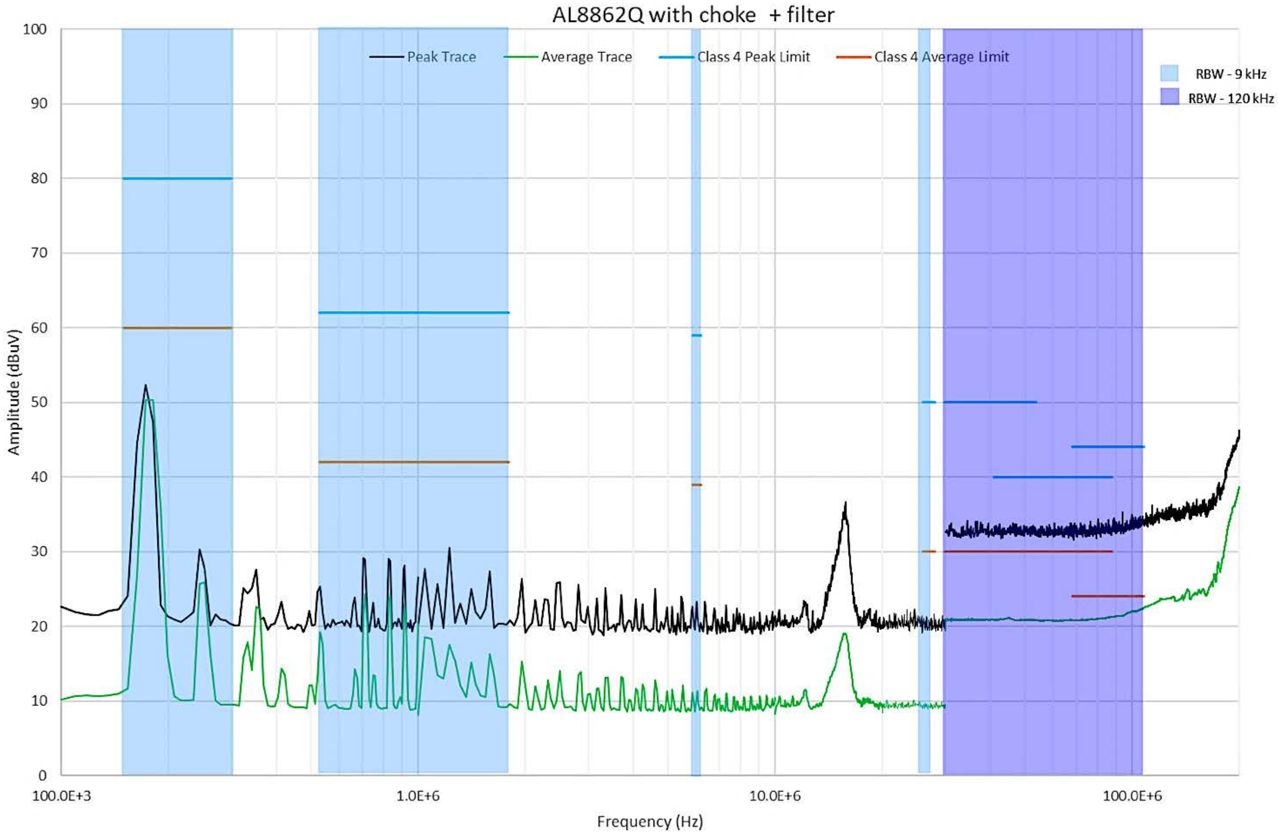

Figure 9: AL8862Q with CM Choke and Filter, 13.5V In, 1A output current, 100kHz – 200MHz

This filter setup passes class 4 confidently, with only 3 additional components.

Conclusion:

This application note has shown a step-by-step method to effectively design an input filter. While we have concentrated on the AL8862QEV1 evaluation board, this methodology can be used to tackle the design of input filtering for almost any DC-DC or switching LED driver. The design of this filter is simple and yet has enabled us to improve the conducted EMC performance from exceeding CISPR 25 class 1 limits to passing class 4 limits, with reductions of as much as 40dBuV. As EMC and efficiency become increasingly important aspects of design. this methodology will help to support designers in implementing efficient switching LED drivers whilst maintaining a quiet EMC environment within the vehicle.

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